SHORELINE CLASSIFICATION OF CONCEPTION BAY AND ADJACENT AREAS

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March 1999

Canadian Technical Report of Fisheries and Aquatic Sciences No. 2274

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report
of Fisheries and Aquatic Sciences No. 2274

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Cat. No. Fs 97-6/2274E ISSN 0706-6457

Correct citation for this publication:

Catto, N.R., M.R. Anderson, D.A. Scruton, J.D. Meade, and U.P. Williams. 1999. Shoreline Classification of Conception Bay and Adjacent Areas. Can. Tech. Rep. Fish. Aquat. Sci. No. 2274: v + 72 p.

CONTENTS

Abstract/Résumé iv

Introduction 1

Regional Setting 2

Classification System 8

Anthropogenic Effects 10

Coastal Classification Zones 11

Summarial Distribution of Shore Classes 43

References 44

Appendix 57

Illustrations 62

ABSTRACT

Catto, N.R., M.R. Anderson, D.A. Scruton, J.D. Meade, and U.P. Williams. 1999. Shoreline Classification of Conception Bay and Adjacent Areas. Can. Tech. Rep. Fish. Aquat. Sci. No. 2274: v + 72 p.

This report classifies the shorelines in the Conception Bay region, extending from Whiteway Bay (Trinity Bay) to Cape Spear, based on study of the 1981 videotape survey held by the Department of Fisheries and Oceans, aerial photograph analysis, and site visits. The coast is dominated by coarse-grained gently to steeply sloping gravel-dominated beaches, and by cliffed shores. Gravel flats and mixed gravel-and-sand beaches and flats are less common. Northern Bay Sands and Salmon Cove represent the only sand-dominated systems. Anthropogenic influence has substantially altered large expanses of shoreline.

Seasonal and yearly variability is characteristic of many of the shoreline systems studied along Conception Bay. Variability hinders effective classification of these systems based on a single time of observation. Textural and morphological fluctuations lead to different classifications of the same system in different years, or at different seasons.

Shorelines generally are dominated by onshore-offshore transport of sediment, with shore-parallel transport playing a lesser role. The influence of shore-parallel transport is locally dominant, particularly at Conception Bay South. Sediments and contaminants have long residence times within individual coves and embayments marked by restricted longshore transport, but residence times along open coastlines are extremely short.

Wind directions are critical in the evolution of shorelines along Conception Bay. Northeast winds are the most effective agents of shoreline erosion and steepening in many areas. Low energy environments persist only in areas where northeast wind activity is not significant. Waves and currents driven by southwest winds are effective in transporting sediment in the southern part of the region.

Sea levels have varied in the region since deglaciation, in response to glacioisostatic factors. A general transgression has been ongoing since the mid-Holocene. Recently, transgression has apparently accelerated, approximating a rate of sea level rise of approximately 6 mm/a. Coastal erosion has become significant in areas where bluffs of Quaternary sediment are exposed to northeast storms.

Future research should focus on particular shoreline systems, and on the impact of seasonal fluctuations and human activities upon individual biological species. Research has demonstrated the necessity of systematic, periodic beach visitation and monitoring. Comparative studies and monitoring of additional beach systems would be desirable.

101-00936/

RÉSUMÉ

Catto, N.R., M.R. Anderson, D.A. Scruton, J.D. Meade, and U.P. Williams. 1999. Shoreline Classification of Conception Bay and Adjacent Areas. Can. Tech. Rep. Fish. Aquat. Sci. No. 2274: v + 72 p.

Dans ce rapport on classe les lignes de rivage de la région de la baie Conception a partir de la baie Whiteway (dans la baie Trinity) jusqu'au cap Spear, d'après l'étude de l'enregistrement sur bande magnétoscopique effectué dans le cadre du levé exécuté en 1981 et tenue par le ministère des Pêches et Océans, d'après l'analyse de photographies aériennes et d'après des visites d'emplacements. La côte est dominée par des plages de gravier à grain grossier faiblement à fortement inclinées et par des falaises. Les plages de sable et de gravier mélangées sont moins communes. Northern Bay Sands et Salmon Cove representent les seules systèmes dominées par le sable.

L'influence anthropogène domine de grandes étendues de la côte. La variabilité saisonnière et annuelle caractérise la plupart des des systèmes côtières autour de la baie. Cette variabilité gêne une éfficace classification de ces systèmes d'après des observations éffectuées en une seule époque. Des fluctuations texturales et morphologiques mènent à des classifications différentes d'un même système observée en des saisons ou des années différentes.

Les côtes sont dominées par le transport des sédiments vers le rivage-vers le large et le transport parallel au rivage ne joue, le cas échéant, qu'un rôle local. Les sédiments et les contaminants peuvent ainsi séjourner longtemps dans des anses et des indentations individuelles marquées par un transport parallel au rivage réduit. Les temps de résidence le long de la côte plus ouverte sont très courts.

L'orientation des vents est un facteur critique dans l'évolution des rivages le long de la baie. Les vents du nord-est sont les agents d'érosion les plus éfficaces dans beaucoup d'endroits. Des environments à faible énergie persistent seulment là ou les vents du nord-est sont faibles. Le transport des sédiments dans la partie sud de la baie s'éffectue par les vagues et les courrants générées par des vents du sud-ouest.

Depuis la déglaciation le niveau de la mer a varié dans cette région en réponse à des facteurs glacioisostatiques. Il y a transgression générale depuis le milieu de l'Holocène. Récemment, la transgression s'est apparemment accélérée pour engendrer une vitesse approximative d'élévation du niveau de la mer de 6 mm par année. L'érosion côtière est devenue significative là ou les falaises Quaternaires sonts exposées aux tempêtes du nord-est.

Les recherches futures devraient êtres axées sur des systèmes littoraux particulières et sur l'incidence des fluctuations saisonnières ainsi que des activités de l'homme sur des espèces biologiques individuelles. Des recherches sur les plages ont démontré la nécessité de visites et d'une surveillance systématiques et a intervalles réguliers. Des études comparatives et la surveillance de plages additionels seraient souhaitables.

INTRODUCTION

In June 1989 a Public Review Panel on Tanker Safety Spills Response Capability was appointed by the Prime Minister of Canada in response to the escalating public concern for the marine environment as a result of accidental oil spills. The Panel was mandated to review and evaluate: i) the measures currently in place to ensure the safe movement of oil and chemicals through Canadian waters, ii) Canada's ability to respond to marine spills of these products, iii) provisions for compensation for damages resulting from spills of oil and chemicals, and iv) Canadian legislation and international conventions which regulate the movement of vessels transporting oil and chemicals.

A major regional need in response planning for marine environmental emergencies is the provision of detailed sensitivity mapping for areas with high potential for such emergencies. One of the areas identified during the Public Review Panel on Tanker Safety Spills Response Capability to have a high potential for an oil-related environmental accident was Placentia Bay, Newfoundland. This elevated risk was due to the presence of an oil refinery at Come-by-Chance. Subsequent to the Panel Report, it has been decided that oil from both the Hibernia and Terra Nova oil fields will be shipped through a new transshipment facility at Whiffen Head, Placentia Bay. It is anticipated that, at peak production, there will be in excess of 350 tanker movements per year in Placentia Bay.

The Panel had found that there was a paucity of sound environmental data in Placenta Bay and recommended that a sensitivity map be prepared. In October 1991, a Treasury Board submission for "Response to Marine Environmental Emergencies (Brander-Smith)" was approved and the Department of Fisheries and Oceans (DFO) was funded to develop the map. One of the required products from this initiative was the establishment of a coastal classification system for Placentia Bay This project was further extended to include the development of a similar system for Conception Bay because of its potential for an oil-related accident due to tanker traffic to fulfil the oil requirements of the thermal generating plant at Holyrood.

This report classifies the shorelines surrounding Conception Bay and adjacent areas, based upon geomorphological and sedimentological criteria. The area investigated includes the entire length of the shoreline of Conception Bay, offshore islands such as Bell Island and Baccalieu Island, the shoreline of northeastern Trinity Bay from Grates Point to Whiteway Bay, and the shoreline of the Atlantic Ocean from Cape St. Francis to Cape Spear (Fig. 1). Classification was accomplished utilizing a videotaped survey of the coastline, conducted in July 1981, which is currently held by the Department of Fisheries and Oceans. Tape references quoted in this report are calibrated by setting the tape counter to zero at Whiteway Bay. A list of tape references for selected localities is provided as Appendix 1. Additional data assisting in classification was provided by aerial photography of the Conception Bay coast, previously conducted by the Governments of Canada and Newfoundland and Labrador, and by military organizations of Canada and the United States.

Previous investigations of the Conception Bay area have been limited. The Atlantic Geoscience Centre has investigated several localities since 1980 (e.g. Forbes 1984, Shaw and Forbes 1987,

Forbes and Taylor 1994). The Topsail Beach area, and the bluffs of Quaternary sediment to the southwest, are the focus of an ongoing programme of monitoring, involving assessment of geomorphic and textural changes and coastal erosion (Liverman *et al.* 1994a,b). On-site investigations ("ground truthing") have been conducted at several coastal locations along the Conception Bay shore by Catto since 1989, and by students under his direction (Prentice 1993, Taylor 1994). These data provide important confirmation of the classifications based on remotely sensed data, allow assessment of hourly, diurnal, seasonal, and year-to-year variations in the morphology and texture of particular beaches, and provide information regarding small- and medium-scale sedimentary features and structures which cannot be viewed from a distance. Integration of the data collected on-site with that obtained from aerial surveys and photography thus completes the spatial and temporal pictures of these shorelines.

REGIONAL SETTING

GEOLOGY AND GEOMORPHOLOGY

The Conception Bay shoreline borders the northeastern part of the Avalon Peninsula. Conception Bay divides the northern part of the Avalon Peninsula into two sub-peninsulas. The St. John's sub-peninsula borders the eastern shore of the bay, and the Carbonear sub-peninsula flanks the western shore. Physiographically, the Avalon Peninsula is classified within the Atlantic Uplands of Newfoundland (Bostock 1970), and is considered to be a part of Appalachia.

The regional geomorphology of the Avalon Peninsula is largely a product of structural geology. The rocks of the peninsula have been deformed by a series of northeast-southwest trending folds and associated faults during the Late Proterozoic - Cambrian Avalonian and the Palaeozoic Acadian Orogenies (King 1988, 1990; Colman-Sadd *et al.* 1990). As a result, the northeast-southwest trending sub-peninsulas are aligned with their long axes paralleling the dominant direction of folding and faulting. The heights of land throughout the Avalon Peninsula follow the axes of the major sub-peninsulas, resulting in the development of drainage systems marked by short, steep gradient streams with small catchment areas. This structural influence is particularly evident in the configuration of the Conception Bay shoreline, especially along its western margin.

Maximum relief in the area surrounding Conception Bay is approximately 270 m, with sea cliffs in excess of 30 m height. The embayments between the sub-peninsulas vary in depth. The maximum depths in Conception Bay (in excess of 280 m), and Trinity Bay (in excess of 580 m) are produced along the structural trends.

The Avalon Peninsula is dominated by Late Proterozoic clastic sedimentary, metasedimentary, and bimodal volcanic rocks, assigned to the Harbour Main, Connecting Point, Conception, St. John's, Musgravetown, Long Harbour, and Signal Hill Groups (McCartney 1967; King 1988, 1990; Colman-Sadd *et al.* 1990). These stratigraphic units each contain a variety of lithologies, and lithologies which dominate any particular Group are frequently encountered in subordinate positions in outcrops of other Late Proterozoic units. For example, although marine sandstone dominates the St. John's

Group, similar marine sandstones are also associated with the Connecting Point, Conception, Musgravetown, Long Harbour, and Signal Hill Groups. Rocks of the St. John's and Signal Hill Groups crop out on the St. John's and Carbonear sub-peninsulas.

Coastal morphology is related to lithology of the adjacent rock outcrops. Sandstone and conglomerate units, such as those associated with the Bay de Verde and Cuckold Formations of the Signal Hill Group, tend to produce steep cliffs, pocket beaches, and embayed coves. Less resistant shale, siltstone, and argillite units, such as the Fermeuse Formation (St. John's Group), are associated with lower cliffs or gently sloping shorelines.

Intrusive igneous rocks of Late Proterozoic to earliest Cambrian age have a limited areal distribution. Although a variety of lithologies are represented, two dominant suites are present. Mafic intrusions, predominantly gabbro, crop out in the Kitchuses area (Whalesback gabbro and equivalents of King 1988). Granitic intrusions, which locally include mafic units, crop out throughout the Holyrood - Witless Bay Barrens area, and south of Harbour Main (intrusive units of Harbour Main Group and Holyrood Intrusive Suite of King 1988). Intrusive rock units are resistant to coastal erosion.

Palaeozoic sedimentary units of the Random Formation, Adeyton Group, and Harcourt Group crop out along the shoreline of Conception Bay (Seal Cove- Manuels, and at Brigus), and along Trinity Bay (Heart's Delight). These units form flat-lying to gently sloping platforms along most shore areas where they crop out. The youngest Palaeozoic rock units of the Bell Island and Wabana Groups form steep cliffs along the shores of Bell, Little Bell, and Kelly's Islands.

CLIMATE

The climate of the region is classified as mid-boreal (Köppen-Geiger Dfb), marked by cool winters and summers and seasonally consistent precipitation (Damman 1983, Environment Canada 1993, Banfield 1993). Daily mean temperatures in Holyrood are - 4° C in January and 15° C in July. January mean temperature values vary little throughout the region, but more variation is evident in the July values, with the northerly areas and those consistently exposed to northeast winds being cooler. Freeze-thaw cycles are numerous from mid-December to early April, and frost events may occur at any time from early September to June. In exposed coastal headlands, several freeze-thaw cycles may occur daily during the early and late winter.

The mean annual precipitation throughout the region varies from 1060 to 1450 mm. Variations are due to aspect, differences in prevailing winds, and differences in the proportion of precipitation types. Areas marked by larger proportions or amounts of snowfall also generally receive less total precipitation. Shoreline areas receive less snowfall and more freezing rain and drizzle, up to 80 hrs/year, than do interior locations. In coastal sites, typically 15-20 % of the precipitation falls as snow, although in exposed regions subject to onshore winds the proportion of snowfall may be less than 10 %. Snow cover persists for approximately 140 days in wooded areas, and for 90-100 days in exposed barrens or logged terrain, but snow is removed rapidly from exposed coastal zones.

Fog is common, but is less ubiquitous on the Conception Bay coast than along the open Atlantic shoreline. The prevalence of fog is greatest in those areas most influenced by southwest winds, such as the open Atlantic coast and southern Conception Bay. North of Harbour Main, fog is less common and is often confined to the deep southwest-trending embayments (such as Bay de Grave and Harbour Grace).

Ice foot development commonly occurs in the winter, and is a major factor in the geomorphic development of the coastline north of Spaniard's Bay. The southerly extent of persistent ice foot development is related to the sea surface temperature and to the extent of drift ice, and appears to coincide approximately with the position of the -0.5° C February SST isotherm. To the north of Spaniard's Bay, several beaches commonly retain an ice foot until late March. Ice foot development does occur on beaches in southern Conception Bay, but it is less extensive, pervasive, and persistent. Adhering ice, however, is common along all beaches which are not anthropogenically disturbed. Offshore pack ice persists from February to April, and icebergs are present along the coastline throughout the spring and early summer.

Wind patterns vary seasonally, and local topographical effects are extremely significant in many embayments. Statistically, southwesterly, westsouthwesterly and westerly winds are more prevalent throughout the year (Banfield 1993). Throughout the region, however, winds may originate from any point of the compass at any time of the year.

The southwesterly winds generally bring warm, moist air to the region from the warmer ocean surface waters south of the Burin Peninsula. In the southern part of Conception Bay, and in the St. John's region, the combination of low topography inland to the southwest (Salmonier Basin area) and the long open fetch of the coast south of Placentia Bay allow the southwesterly winds to be effective climate agents in coastal development. Strong southwesterly winds are associated with many of the major storms and hurricanes during the summer and autumn. During 1995, the enhanced frequency of hurricanes caused southwesterly wind activity to be particularly effective in modifying shorelines.

In the northern part of the Conception Bay region, the combination of the reduced fetch of northern Placentia Bay and higher topography along the spine of the Carbonear sub-peninsula, in the Heart's Content Barrens area, reduces the effectiveness of southwesterly and westerly winds. In this area, the dominant winds responsible for storm modification of shorelines are the northeasterlies, associated with the autumnal gales. Strong northeasterly gales in late September - early October 1992 modified many beaches along the northern part of the Conception Bay coastline, and further modification resulted from the somewhat weaker (but substantial) storms of autumn 1994. Northeasterly winds are also effective agents of shoreline modification in the southern part of Conception Bay, and along the open Atlantic shoreline.

Winds from other points of the compass do occur and, locally, may act to modify shorelines. Southeast winds have their greatest influence north of Broad Cove, in areas where fetch is not restricted by Bell Island. Northwest winds are significant in northeastern Trinity Bay, and occasionally along the Conception Bay South and northwestern Bell Island shores. Diurnal onshore and offshore winds are common in most embayments.

In contrast to the random pattern of current motion which characterizes the centre of Conception Bay, currents in nearshore areas generally follow a counter-clockwise circulation pattern, moving southward from Baccalieu Island to Holyrood and northeastward to Cape St. Francis. Considerable local variation exists, however, especially in the embayments. The currents in the vicinities of Bell and Baccalieu Islands are particularly influenced by the local bathymetry. Open beach areas, such as Topsail, are dominated by a net shore-parallel transport, although variations due to shore-normal motion and edge wave activity exist and may dominate for several days at a time. Some coves are dominated by shore-parallel transport, but in the majority, onshore-offshore sediment movement, essentially normal to the beach, dominates. Along all beaches and in many coves, current patterns shift in response to changes of wind direction and to storms. Conditions thus vary diurnally, seasonally, and annually.

TERRESTRIAL VEGETATION

Terrestrial vegetation throughout the low-lying and sheltered parts of the region is dominated by coniferous boreal forests, with *Abies balsamea, Picea glauca, Picea mariana,* and *Larix laricina* (Heringa 1981, Damman 1983, Ryan 1978). Deciduous species include *Populus tremuloides, Betula papyrifera, Betula pumila, Sorbus decora, Prunus pensylvanica, Alnus spp.*, and *Salix spp.* Scattered coastal areas contain patches of tuckamore, *Picea glauca.* Many areas which formerly supported vegetation have been cleared for agriculture, logging, or domestic woodcutting.

Denudation has substantially changed the hydrologic regime of the interior areas, greatly affecting the quantity and timing of freshwater and sediment influx to Conception Bay. Additional forest losses in the past 20 years due to fire (Heart's Content - Western Bay area) and insect predation (hemlock looper and European pine sawfly in the south and east; spruce budworm along Trinity Bay) have also resulted in increased sediment supply to the coastal areas.

Plateaux, and plains in exposed locations overlooking the shore, are dominated by ericaceous vegetation, including *Empetrum spp., Vaccinium spp., Mitchella repens, Rubus chamaemorus,* and *Ledum groenlandicum.* Other common plants are *Juniperus communis, Cornus canadensis, Kalmia angustifolia, Kalmia polifolia,* and *Rhacomitrium* moss. Vegetation cover in these areas, although low-lying, is generally continuous where undisturbed.

QUATERNARY GLACIAL HISTORY

The entire shoreline of Conception Bay was glaciated during the Quaternary period (Henderson 1972, Grant 1989, Liverman and Taylor 1990). The Avalon Peninsula supported its own independent ice caps throughout the Late Wisconsinan. Ice from the main part of Newfoundland flowed seaward through Trinity Bay, but was confined to the westernmost coastal fringes. The remainder of the Conception Bay region was influenced exclusively by locally derived glaciers. The distributions of sediments and landforms in the Conception Bay region have been investigated and mapped by Catto (1992, 1993a, 1994a). Analysis of the available data has revealed a complex pattern of glaciation

throughout the Avalon Peninsula, marked by shifting accumulation areas and variable directions of flow. Three major phases of glaciation, each involving several distinct ice centres, can be recognized (Catto 1995, Catto 1998).

During the initial phase, ice advancing from centres located in the Heart's Content Barrens and the headwaters of Western Bay Brook covered the Carbonear Sub-Peninsula north of Harbour Grace. Ice flow from centres at White Hearts Pond (south of Markland) and Franks Pond (Avalon Wilderness Area) reached the Conception Bay shoreline between Harbour Grace and Black Ridge (northwest of Holyrood). The Conception Bay South area was covered by ice originating from the Witless Bay Barrens, flowing northwestward across the bay to cover Bell Island.

The second phase of glacial activity represented the maximum extent of ice. Glacial ice inundated all of Conception Bay during this phase, depositing a discontinuous veneer of diamicton in most areas. Flow was generally to the east and northeast, and originated from distinctive centres in the Heart's Content Barrens, Witless Bay Barrens, and northern St. Mary's Bay.

The subsequent deglacial phase of ice flow activity was marked by the collapse of the major ice flow centres, and the initiation of flow from several short-lived ice centres in the headwaters of Northern Bay Brook and on the Bay de Verde Peninsula. Flow also continued from the ablating centres on the Heart's Content Barrens, and on the Witless Bay Barrens. Although this event was the most recent glacial phase to affect the entire Avalon Peninsula, including the Conception Bay shoreline, its effect on the landscape was limited in most instances.

The final deglaciation of the Avalon Peninsula is constrained by a ^{14}C date of 10,100 ± 250 B.P. (GSC-3136) from Golden Eye Pond in the Hawke Hills (Macpherson 1995). The requirement for vegetation to reach and become established on the Avalon Peninsula (Macpherson 1982), necessitating transit along the southern coast of Newfoundland, suggests that the actual date of deglaciation was prior to 10,100 ± 250 B.P.

Diamictons associated with all three glacial phases and those which have been subsequently reworked and re-mobilized are characteristically coarse-textured, with silt concentrations of <2 % - 30 %, and large clasts (pebbles, cobbles, and boulders) comprising 30 % - 55 % of the sediment (Henderson 1972, Catto and Thistle 1993, Catto and St. Croix 1998). The diamicton assemblages are dominated by debris flow and slurry flow deposits, with other reworked sediments. Although the material was most likely initially deposited as till, it has undergone substantial amounts of reworking since the initial deposition. Therefore, most deposits do not preserve a primary glacial signature, and hence cannot be regarded as "till".

Glaciofluvial gravel and sand units are present at several locations along the shoreline of Conception Bay. The largest expanse of glaciofluvial sediment flanks the coastline from Topsail Beach southwestward to Holyrood, locally forming bluffs to 25 m height. These sediments form a series of laterally coalescent kames and kame deltas, developed as meltwater debauched northward from the retreating glacier standing along the margin of Conception Bay. The glaciofluvial deposits are locally capped by peat veneers and blankets, as at Upper Gullies and Seal Cove (Catto 1994a, Catto

and St. Croix 1998). Their presence along the coastline of Conception Bay has contributed to the susceptibility of this area to coastal erosion, and to the development of gravel-dominated mixed sediment shoreline features.

SEA LEVEL HISTORY

Sea levels throughout the Conception Bay region have undergone a series of changes since deglaciation. Initially, sea levels were higher than present around the shoreline of Conception and Trinity Bays. Higher sea levels carved erosional benches and deposited gravel terraces at elevations between 5 m and 20 m above the current sea level, with the northwestern shore suffering the most inundation and the southern tips the least. This pattern, due to the effects of glacioisostatic depression emanating from the much larger Laurentide inlandsis to the northwest, forms part of a general distribution of shorelines steadily increasing in elevation towards the northwest throughout coastal Newfoundland (Liverman 1994).

Subsequently, sea level fell around the Conception Bay coast, dropping to at least 10 m below present during the early Holocene (Grant 1989; Shaw and Forbes 1990, 1995; Liverman 1994; Shaw *et al.* 1994). The decline in sea level is attributed to a reaction from glacioisostatic over-compensation, following the "Type B" model proposed by Quinlan and Beaumont (1981, 1982).

Early Holocene sea level history was substantially different along the open Atlantic coastline south of Cape St. Francis, where raised marine features have not been recognized. Cores taken from St. John's Harbour indicate that a freshwater lake existed shortly after deglaciation, c. 11,000 years B.P. (Lewis *et al.* 1987). This suggests that sea level at this time was at least 14 m below present, the elevation of the controlling sill in The Narrows. Marine transgression is recognized by a transition from a brackish thecamoebian *(Centropyxis aculeata)* to a marine foraminiferal assemblage, c. 9,900 years B.P.

Sea level in St. John's Harbour appears to have remained below present throughout the Holocene, but at other sites along the Southern Shore, a short latest-Holocene transgressive phase is tentatively inferred from geomorphic evidence (Catto 1993b; 1994a, b; 1995). No raised marine deposits have been encountered in excavations in downtown St. John's, although marine deposits at elevations to 5 m above sea level are present along the southern shore of Conception Bay at Portugal Cove, St. Philips, and Conception Bay South (Brückner 1969, Catto and Thistle 1993, Catto and St. Croix 1998).

The latest Holocene has been marked by rising sea levels around the entire Avalon Peninsula. Building foundations uncovered by archaeological excavations currently in progress at Ferryland, along the Southern Shore, suggest that sea level may have been ± 3 m lower than present in the early 1600's (Catto 1993b, 1995). A similar rate of rise is suggested by artifacts at Fort Frederick, Placentia.

At Mobile, south of St. John's, a submerged forest of *Picea* stumps was exhumed as a result of storm action in 1994 (Jones 1995). Eleven stumps have been identified to date, with bases extending to 0.5

m below low tide level, and several are exposed at low tide along the beach. ^{14}C dating of the outer rings of one rooted stump indicated an age of 310 ± 50 B.P. (GSC-5836). As spruce cannot survive if their roots encounter salt water, the presence of these stumps indicates that sea level was at least 2 metres lower than present ç 300 years ago (Catto 1995). Sea level has therefore risen along the Atlantic shoreline of the Avalon Peninsula at a rate of at least 6 mm/a, a value similar to those inferred from the archaeological data at Ferryland and Placentia. Regardless of the relative importance of anthropogenic and natural factors contributing to sea level rise (Kemp 1991), or of the regional climatic signal (Pocklington *et al.* 1994), sea level is rising along the Conception Bay shoreline.

Coastal erosion accelerated by rising sea levels has occurred along the Conception Bay coast, notably in Conception Bay South (Taylor 1994, Liverman *et al.* 1994a, b). As in other regions (Jones and Williams 1991, Jones *et al.* 1993, Komar and Shih 1993), changes in the rate of removal of sediment are most effective at accelerating shoreline erosion. Although the dimensions of the problem are not as severe as along the south coast of Nova Scotia (Taylor *et al.* 1985, Shaw *et al.* 1993, 1994), local property losses due to coastal erosion have occurred.

CLASSIFICATION SYSTEM

The classification system used in this report follows that used by the Department of Fisheries and Oceans in other regions of Newfoundland and Canada, including the Placentia Bay region (Catto *et al.* 1997). This system was initially based on the schemes proposed by John Harper for the Pacific Coast of Canada, and by SeaConsult Ltd. for the west coast of Newfoundland. The classification system is outlined in Table 1. Although difficulties have been observed in the application of this scheme to the Conception Bay region, as are outlined below, it has been retained in the interests of regional consistency and to facilitate comparisons with other, similarly mapped shores (particularly those of Placentia Bay).

Adoption of any classification system creates potential problems for users. A classification scheme represents a first approximation of nature, and hence is prone to error and over-simplification. Those scientists who are devoted to the development of classification schemes as a primary focus of their work are often involved in mutual recriminations and denunciations. Development of a usable classification of coastal and shoreline systems requires understanding of the temporal variability of the natural environment.

To be of value, a good classification scheme must be appropriate for the task involved. Schemes designed exclusively for academic purposes, incorporating particular parameters, may not be appropriate for technical applications or be useful for coastal land management. Likewise, schemes designed to classify and explain coastal zones over "geological" time intervals (>10,000 years) may give unsatisfactory results when applied over shorter time spans. This is especially evident in situations where a combination of recent climate change and human utilization of coastal zones has resulted in changes in sedimentation and geomorphology.

Classification based on short-term observation of the shore may fail to describe fluctuations over longer terms. Most classification systems assume that classification will be based on a single observation of the coast (e.g. during an aerial survey operation, such as that conducted in July 1981 for Conception Bay), and that conditions will not vary substantially throughout the seasons or from year-to-year. Observations of several of the beach systems throughout the study region, in addition to those observed in other parts of Newfoundland (e.g. Prentice 1993; Forbes *et al.* 1993, Boger 1994; Catto 1994b, c; Liverman *et al.* 1994a,b; Nichols 1994; Hicks 1995; Jones 1995; Catto *et al.* 1997, Catto 1997) indicate that the assumption of relatively constant sediment textures and shoreline morphology throughout the interval from 1981 to 1995 is not valid. Transitions, both spatially and temporally, are common. Further changes are evident for those regions where older aerial and ground-level photographs provide a record of events. In some areas, the changes are significant enough to entirely change the shoreline classifications that would be determined at different times. These shorelines are designated with compound symbols in this report (e.g. 14 / 17).

A second problem is that the individual classes within the system encompass different ranges of variability of morphology and sediment texture. A Class 23 (estuary and fringing lagoonal) shoreline, for example, incorporates many small zones varying in texture and morphology, such as individual tidal channels, fluvial bars, areas of bank erosion and deposition, and vegetated and unvegetated zones. In contrast, steep beaches (Classes 6, 9, 15, and 18) show much greater homogeneity.

Designation of a shore area as Class 23 also entails consideration of terrain inland from the water's edge, in contrast to the designation of a steep beach or a gravel flat, both of which will be covered with marine water during storm events. Problems are thus encountered when cross-shore variations are considered. Although the classification scheme adopted is designed primarily to reflect conditions at the water's edge, in many instances cross-shore variability is important when considering sediment supply, seasonal changes, and overall stability of the segment of shoreline. In this report, the impacts of cross-shore successions are considered in the discussion of individual shoreline classes and specific examples. Detailed analysis of the impact of cross-shore variations would require intensive study of individual beach segments.

Cliffed shorelines are assumed to be dominated by bedrock cliffs in the classification scheme. Along some parts of the Conception Bay shore, however, steep sediment bluffs in excess of 10 m high back gravel beaches or narrow gravel flats. The sedimentary cliffs may form isolated bluffs flanked by depressions, as at Harbour Grace and in the north part of Carbonear Harbour, or may be present as continuous bluffs, as along the 'Backside' area of Bay Roberts. These bluffs supply sediment to the beach areas during storm events, and in areas where the vegetation is anthropogenically disturbed. The beaches and gravel flats developed in association with these bluffs differ in terms of stability and morphology from those present at the bases of bedrock cliffs.

The definitions of textural subdivisions pose a potential problem to users of the system. In geological or sedimentological terms, "gravel" is defined as all materials of granule size or coarser, ranging from 2 mm diameter to the largest boulders, following the Wentworth-Udden textural classification system of 1898 - 1922. Clasts between 2 mm and 1 / 16 mm (0.0625 mm) are defined as "sand". Thus, a "gravel" beach could theoretically be composed entirely of granules, or entirely of boulders, or have

a textural assemblage of a variety of gravel classes. A beach, in order to be considered as a sand-dominated system, must have a volumetric majority of clasts of grain diameter < 2 mm. Many beaches considered suitable for capelin spawning, such as Caplin Cove, are thus classified as gravel beaches and contain very small proportions of sand (especially after storm events). The number of true sand beaches, therefore, is perhaps lower from the sedimentological perspective than from the perspectives of other users.

In this report, textural classifications are accompanied where possible by discussion of the relative proportions of the grades of gravel and sand. Following the standard Wentworth-Udden classification, gravels are subdivided into "granules" (2 - 4 mm diameter), "pebbles" (4 - 64 mm in diameter), "cobbles" (64 - 256 mm in diameter), and "boulders" (> 256 mm in diameter). Pebbles and cobbles may be further subdivided into fine, medium, and coarse grades. Sand is subdivided into "coarse" (0.5 mm - 2 mm in diameter), "medium" (0.25 - 0.5 mm in diameter), and "fine" (0.0625 - 0.25 mm in diameter) grades. Clasts between 0.0039 mm and 0.0625 mm in diameter are considered as "silt", and those less than 0.0039 mm in diameter are "clay". The term "mud" encompasses both silt and clay.

ANTHROPOGENIC EFFECTS

Anthropogenic modification of the shoreline is not explicitly considered as a classification unit in this system. In one sense, human activity can be regarded simply as the mechanism by which a new shoreline class is created, and the resulting shore treated as any other (ie., a shoreline backed by a concrete wall can be compared to one backed by a resistant bedrock cliff). For other purposes, however, anthropogenic activity significantly alters the physical characteristics of the shoreline (Nakashima and Mossa 1991, Titus *et al.* 1991, Kelletat 1992, Pilkey *et al.* 1993, and Anthony 1994), inducing changes that have not finished propagating through adjacent areas, in addition to the biological effects. In the Conception Bay region, significant modification of the shoreline by direct human intervention is evident in numerous areas, and anthropogenic impact along this shoreline equals or exceeds that in any other area of Newfoundland.

Anthropogenic influences on the physical attributes of shorelines are most evident in St. John's and the smaller urban centres of Carbonear and Harbour Grace, but are apparent in many other communities. In the study region, anthropogenic activities resulting in modification of shorelines include:

- deliberate construction of breakwaters, or modification of preexisting spits and bars (e.g. Port de Grave, Chapel Cove, Old Perlican). In some areas, modification of the original coastline continues to induce changes, although the original infrastructure has disappeared (King's Beach, Harbour Grace);

- dredging to improve navigation and access (e.g. Ochre Pit Cove, Manuels);
- construction of wharves and stages;

- construction of groynes to retard sediment erosion and beach-parallel transport (Harbour Grace);
- construction of seawalls to restrict wave erosion (Carbonear, Clarke's Beach, Spaniard's Bay);
- railroad construction (Holyrood, Kelligrews, Seal Cove, and Carbonear, as well as other localities);
- road construction (Bristol's Hope, Coley's Point Long Pond, the 'Coish' near Bay Roberts);
- construction of industrial infrastructure, as at the Holyrood refinery;
- extraction of beach aggregate, either through 'official' or regulated operations (Topsail, Seal Cove), or on a casual basis;
- use of beaches for domestic purposes, such as capelin harvesting and rockweed gathering;
- use of beaches for recreation (Northern Bay Sands, Salmon Cove, Middle Cove); and
- regulated disposal of domestic and commercial wastes and sewage, and unauthorized waste disposal.

The population of the Conception Bay region, exclusive of metropolitan St. John's - Mount Pearl - Conception Bay South, exceeded 60,000 people in 1991. More than 90 % of the total population of the Avalon Peninsula live in the vicinity of the studied coastline. Anthropogenic impact in this region, therefore is much greater than along less densely settled shorelines, such as those of Trinity or Placentia Bays. In some areas, anthropogenic activity has been an active force in shoreline modification for more than 100 years, precluding establishment of the 'original' character of the coast prior to disturbance.

COASTAL CLASSIFICATION ZONES

CLASS 1 -- WIDE ROCK PLATFORM

The wide rock platform class is defined as a bedrock platform, largely or totally devoid of sediment, which slopes seaward at a shallow angle (< 20°) and is in excess of approximately 30 m in width. In other coastal regions of Atlantic Canada, such platforms are generally associated with gently dipping sedimentary (St. Andrews, NB), metamorphosed sedimentary (east coast of Grand Manan Island, NB) or extrusive volcanic strata (parts of Brier Island, NS), in areas with limited sediment cover inland. Broad platforms are frequently associated with upper mesotidal or macrotidal regimes, as is the case for all of these examples along the margins of the Bay of Fundy. In areas marked by mesotidal or microtidal conditions, such as Conception Bay, sediment fluxes from either landward or seaward sources would have to remain low to keep the platform exposed.

Seasonal ice activity, as occurs along the Northern Peninsula of Newfoundland at St. Barbe, Flower's Cove, Eddies Cove, Cape Norman, and at numerous other locations in northeastern Newfoundland (Forbes and Taylor 1994, Hicks 1995), can also act to remove sediment and expose wide rock platforms. In some locations, the influence of seasonal ice shove results in the construction of a boulder rampart, or the emplacement of individual boulders perched on the rock substrate. Seasonal

ice activity, however, cannot totally denude a rock platform which is routinely subjected to sediment influx from the adjacent land area. In addition, the impact of seasonal ice activity is directly related to tidal range, with greater effects evident in macrotidal areas (Ungava Bay, Cumberland Sound: Gilbert and Aitken 1981, Owens and Harper 1983, Gilbert 1990) than in microtidal regions.

The combination of steeply dipping bedrock, locally high sediment fluxes, and microtidal conditions throughout much of the study region effectively preclude development of this style of coast. Areas with gently dipping bedrock are commonly associated with abundant onshore sediment sources. The only example of a Class 1 zone is located at Flatrock (Illustration 1), on the open Atlantic coast (St. John's map sheet, tape reference 5740-5752)[1]. Here, resistant red conglomerate of the latest Precambrian Signal Hill Group (King 1988) slopes seaward at angles of 10° - 30°. Where the conglomerate is exposed to waves and drifting seasonal ice originating from the northeast, sediment is routinely removed, exposing the platform and allowing erosion to occur. Although individual boulders transported by ice shove exceed 50 cm in diameter, erosion is primarily due to frost activity over the periodically exposed rock surface. The margins of the coarse clasts within the conglomerate accentuate frost weathering, and wave action (with some gravitational rolling) rapidly removes the debris. Periodic removal of painted surfaces suggests that the mean erosion rate is on the order of $\leq$ 1 mm/year, although most erosion appears to take place by plucking of individual clasts.

Exposure is generally greatest following the early spring. Small amounts of sediment cover ranging from 10 - 35 % gradually accumulate throughout the summer months, and are partially removed during autumn storm events. The lateral extent of the exposed rock platform has varied throughout the 1980's until 1995, in accordance with the degree of ice shove activity and the prevalence of northeasterly storm winds. In years marked by large amounts of ice shove (spring 1991), the lower part of the platform is swept completely clean of sediment, and the boulders form several lines across the upper part representing different ice shove events. In years when ice shove activity was less (spring 1993), no boulders may be present above mean high tide level.

CLASS 2 -- NARROW ROCK PLATFORM

The narrow rock platform class is defined as a bedrock platform, largely or totally devoid of sediment, which slopes seaward at a shallow angle (< 20°) and is less than 30 m in width. Such platforms may develop in areas of moderately to steeply dipping sedimentary or volcanic bedrock, or in areas of metasedimentary bedrock, both of which occur in several areas of the Conception Bay region. Inland areas are frequently marked by limited sediment cover, but the narrowness of the platform facilitates removal of sediment by marine processes, and hence more sediment may be present inland than is the case for Class 1 shores. Sediment fluxes, however, are generally low. Narrow rock platforms can develop in all tidal regimes, and under a variety of sea ice conditions.

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[1] *Tape references refer to the reconnaissance tapes produced by Mobil Oil Ltd. in 1981. Reference figures are calibrated by setting the tape counter to zero for Whiteway, Trinity Bay.*

The development of these platforms is primarily the result of frost weathering during intervals when the rock is exposed, rather than being the product of direct abrasion by waves or sea ice. The rate of formation is thus controlled by the number of freeze-thaw cycles, rather than by the intensity of marine activity, and hence is climatically dependent. Along the Avalon Peninsula shore, conditions are ideal for the formation of rock platforms at elevations ranging from mean low tidal position to several metres above present sea level. In the study area, platforms as high as 10 m above the present sea level are actively undergoing erosion and modification at present. The presence of a rock platform at an elevation above sea level in an exposed coastal situation thus cannot be considered as evidence for a former high stand of the Atlantic Ocean. Similar phenomena responsible for active rock platform formation above mean sea level have been noted in different climate regimes (e.g. Johnson 1933, Trenhaile 1987), and complicated shorelines with alternating pocket beaches, cliffs, and platforms are common (e.g. Scott and Johnson 1993).

Narrow rock platforms occur along several segments of the coastline of the Conception Bay region. Along Island Point Cove, Trinity Bay (Old Perlican map sheet, tape reference 0950-0968), rock platforms interspersed with gravel beaches (Class 5) occur along an 800 m expanse of shoreline. The platform has developed where the Maturin Ponds Formation (King 1988), composed of friable red shale, sandy siltstone, and silty sandstone, dips seaward at 20°-25° towards the northwest and is overlain inland by coarse grained glacigenic diamicton. Northwest winds act to rework frost wedged debris derived from the surface of the rock platform and from the glacigenic deposits. The wave-transported pebbles and fine cobbles are concentrated into patchy gravel beaches varying from 25-100 m in length. Irregular, discontinuous ridges of gravel 0.5-2 m high oriented in poorly defined arcs convex to the shoreline mark the sediments from sea level to 10 m asl on a transitory basis. The intervening bare rock areas at these levels appear to be actively undergoing erosion. The bare rock platform areas have represented between 50 % and 85 % of the shoreline throughout the previous 30 years. Variations in the extent of sediment cover are related to the prevalence and strength of the northwest winds. During periods of lesser wind activity from the northwest, the gravel beach ridges are lower, and the gravels cover larger expanses of the rock platform. Northwest winds act to focus gravel deposition, creating the ephemeral arcuate ridges. A similar rock platform/gravel beach assemblage is developed on the Maturin Ponds Formation at Abraham's Head, to the southwest (Tape reference 0915). The appearance of both these areas, and potentially hence their classification varies dependent on the strength and prevalence of northwest wind activity.

Rock platforms are also present in the Bay de Verde area (tape reference 1470-1488). These platforms are developed on the red coarse sandstone pebble conglomerate of the Baccalieu Member of the Bay de Verde Formation. In most areas, the Baccalieu Formation is resistant to erosion, forming steep cliffs with local fringing gravel beaches. At Bay de Verde, however, the rocks have been deformed into a doubly-plunging syncline (King 1988), creating a low 'saddle' which has subsequently been eroded to form Bay de Verde harbour. In the basinal area of the syncline, dips of rock units reach 0°, allowing the development of the rock platform and the harbour. Similar effects are present to the southwest, at Low Point (1530). In contrast, areas along the synclinal axis which are not associated with 'saddles', such as Horns Point, and those associated with the adjacent anticlines (Flambro Head; 1575), are marked by steep bedrock cliffs.

Narrow rock platform shorelines are located along the shore from Upper Small Point southwest to Perry's Cove (Kingston area, tape reference 1887-1900; Illustration 2). These platforms are associated with friable grey-green shales and siltstones of the Conception Group, in areas along fold and flexure crests. Numerous small flexures are present in this area, forming an undulatory pattern of rock platforms separated by low cliffs and sediment-covered zones. In this area, bedrock geology is the dominant control on morphology and sediment distribution, and the position and extent of the bare rock platform areas remains essentially constant throughout the year.

CLASS 3 -- ROCK CLIFF

Rock cliffs are a ubiquitous feature of the Conception Bay shoreline, occurring along virtually all segments of the coast. Cliff heights vary from less than 5 m to greater than 60 m. Typical examples are found northeast of Winterton, Trinity Bay (0704-0770); around Baccalieu Island (not shown on tape); at Red Head, Flatrock (5740-5752; Illustration 3); and at Redcliff Head (5720-5730). Cliffs range in slope from 30° to vertical. Local examples of overhanging cliffs, caves, and offshore arches and stacks are present (e.g. Hant's Head 10770; Small Point 118701).

All cliffed areas, regardless of cliff height, supply large quantities of sediment to the marine system as a result of frost wedging. Frost action is the dominant weathering process along the entire Conception Bay coast. The rate of frost wedging is contingent upon the tensile strength of the rock units and the number of fluctuations about 0°C (see Trenhaile and Mercan 1984, Trenhaile 1987). The jointed, fractured, and bedded nature of much of the Precambrian and Palaeozoic bedrock facilitates wedging, and the repetitive temperature fluctuations about the 0°C mark, characteristic of the winter and spring climate of the region facilitate rapid breakdown of the rock. The tensile strengths of late Precambrian argillites and sandstones which crop out over the Avalon Peninsula, and of the Palaeozoic sediments of Bell Island, are on the order of 10 - 20 % of the 1.4×10^6 kg / m^2 stress imparted during the process of ice crystallization. The most resistant rocks in the region, unfractured limestone of the Manuels River Formation and igneous units of the Holyrood Intrusive suite and Harbour Main Group, have tensile strengths less than half of the frost-induced stress. Thus, even unfractured bedrock in the region is unable to resist frost wedging. Weathering by all other mechanical and chemical processes is insignificant by comparison, a consequence of the geology and boreal climate of the coast.

Mechanical erosion of the cliffs also contributes substantial quantities of sediment to the marine system. Most erosion is accomplished directly by running water, with sea ice scour playing an insignificant role along all bedrock cliffed coasts along Conception Bay. Wave action has relatively little direct erosive impact on the cliffs. Notches up to 3 m asl are present along some segments of cliffed shoreline (e.g. Broad Cove - Adam's Cove; Heart's Content map sheet, tape reference 1830-1862), but these are associated with anomalously friable bedrock units and are eroded by frost wedging of spray. Notches and erosional features in the cliffs cannot be related to phases of higher sea level.

Cliffed shorelines are associated with resistant rock units that strike oblique to the coastline. At Flambro Head (1575), the steep cliffs along the northern side of the peninsula are associated with the medium-coarse grained Gibbett Hill sandstone (Signal Hill Group), a highly resistant unit. Along the southwest side of the peninsula, the Gibbett Hill Formation parallels the coast, and is flanked by the more easily eroded Old Perlican siltstone and fine sandstone; the shoreline location approximates the contact between the bedrock units. Similarly, resistant rock units are responsible for shoreline configurations at Western Bay Head (Renews Head sandstone; 1786), on Baccalieu Island (Baccalieu conglomerate), and at several other locations.

Faulting is also responsible for cliffed shoreline development. At Brigus, the Brigus Fault trends north-south across the harbour. Local erosion along the fault contact has produced the westward-facing cliffs at Gallows Cove (north side; 3636-3640) and Frogmarsh (south side; 3700). The more friable argillites and shales of the Fermeuse Formation in the harbour area have been eroded more rapidly than the resistant igneous units of the Harbour Main Group to the east.

The longest segment of cliffed shoreline is present along the eastern side of Conception Bay from Topsail Head north to Cape St. Francis (tape reference 5180-5576). Throughout this 35 km length of shoreline, road access to Conception Bay is only possible at St. Phillips, Portugal Cove - Beachy Cove, and Bauline. The lack of indentations and high cliffs are due to the presence of the resistant igneous rocks of the Harbour Main Group, which with the exception of Portugal Cove - Beachy Cove (5298-5310), armours the shoreline throughout its length.

Cliffs are also developed in the Ordovician sandstones and shales of Kelly's, Little Bell, and Bell Islands (Bell Island and Wabana Groups). These ferruginous sediments are highly susceptible to frost wedging, due to their well-developed bedding and orthogonal jointing. In most locations, the frost-wedged debris is rapidly removed by wave action, resulting in steep cliffs flanked by small talus aprons extending to the water's edge. In areas where the talus can accumulate undisturbed, talus cones with slopes up to 40' are present.

CLASS 4 -- GRAVEL BEACH ON WIDE ROCK PLATFORM
CLASS 7 -- SAND & GRAVEL BEACH ON WIDE ROCK PLATFORM

Class 4 shores are defined as those which have a gravel beach, composed primarily of pebbles, cobbles, and/or boulders, superimposed on a wide, gently sloping bedrock platform. Class 7 shorelines are differentiated from Class 4 shorelines on the basis of texture. In this report, a Class 7 shoreline is defined as a beach which contains between 30 % and 70 % sand (determined either from visual estimates or *in situ* sampling), and is developed on a wide rock platform.

The morphology of both Class 4 and Class 7 beaches is predominantly controlled by the bedrock. The sediments form a veneer or blanket over the bedrock, patches of which are infrequently exposed. The extent of sediment cover is generally greater for a Class 7 than for a Class 4 shoreline, but seasonal variations and topographic irregularities can produce areas of exposed bedrock platform flanked by sediment-covered segments (Semeniuk *et al.* 1988). The beaches accumulate over the

widest areas of the platforms. This results in areas with alternating shoreline segments classified as bare rock platforms (Class 2), gravel beaches on wide rock platforms (Class 4) and narrow rock platforms (Class 5), and mixed sand and gravel beaches on wide (Class 7) and narrow (Class 8) platforms. Frequent gradations and seasonal variations among these classes is to be expected.

The scarcity of wide, gently sloping rock platforms along Conception Bay, and the limited supply of sand effectively preclude development of both Class 4 and Class 7 shorelines. The Perry's Cove area (Heart's Content map sheet, tape reference 1916-1926) is the only shoreline in the study region which displays beach development on a wide rock platform (Illustration 4). This area is marked by alternating segments of bare rock platforms and beaches of seasonally variable texture.

The complex at Perry's Cove extends for 1600 m. Beaches on wide rock platforms developed in the Renews Head Formation are present at five locations, separated by segments on narrow rock platforms (Classes 5 and 8). The Class 4 and 7 beaches are generally aligned facing south and southeast, which limits their exposure to the strongest waves generated by northeasterly gales. Segments of rock platforms facing northeast are generally narrow and marked by limited beach development.

The segments designated as Class 7 beaches at Perry's Cove and Spout Cove (Illustration 7) contain more gravel (65 - 85 %) than sand (15 - 35 %). Gravel clasts are predominantly pebbles, and the sand is medium to coarse-grained. The clasts associated with the Class 4 gravel beaches are generally coarser (coarse pebbles - fine cobbles), and sand is not present. Yearly, seasonal, and daily variations in texture, involving removal of sand and mobilization of granules, pebbles, and fine cobbles, are evident throughout the area, but beds of fine-grained sand are not present. Slopes on the beaches range from 5° - 22°, and the angle of slope is generally proportional to the dominant clast size.

Variations in beach texture are controlled primarily by differential sediment fluxes generated from both terrestrial and marine activity, but are not related primarily to wave energy levels. High energy events remove sand from all beaches, causing the development of gravel forms, but sand accumulation is largely due to input from the land in the intervals between storms. Sand is derived from the glacigenic and colluvial diamictons exposed above the bedrock along the shore, and is transported to the coast by colluviation associated with spring runoff and bank collapse (some anthropogenically-triggered), and by Perry's Cove Brook. Consequently, the proportion of sand in the area's beaches is controlled primarily by location with respect to terrestrial sediment sources, and secondarily by the period which has elapsed since the most recent high wave event.

CLASS 5 -- GRAVEL BEACH ON NARROW ROCK PLATFORM

Class 5 shores differ from Class 4 in that they are developed on narrow rock platforms, generally marked by slightly greater slopes. The two classes may form in similar situations, and may grade laterally into each other (as at Perry's Cove). In high mesotidal or macrotidal environments, the status of the tide may affect classification if it is based on only a single observation, but microtidal shorelines such as those in the Conception Bay region pose no difficulties in this regard. Individual Class 5

shores viewed by direct observation and on photographs taken at different times showed little variation attributable to tidal status, but seasonal variations are common at sites dominated by pebble-sized gravel.

Class 5 shorelines may develop in lower energy positions adjacent to higher energy zones marked by narrow bare rock platforms (Class 2). An assemblage of this type occurs in the Grates Cove area (Bay de Verde map sheet, tape reference 1300-1305). Grates Cove is exposed to winds from the northeast and northwest quadrants, but the effect of northwesterly winds is dominantly felt on the eastern side of the cove. In this area, resistant coarse sedimentary rock of the Bay de Verde Formation is slowly being eroded. Debris is swept east-northeastward by the predominant current in the embayment, and is carried away from the shoreline towards Baccalieu Island. This zone is sheltered from direct northeasterly winds, and thus undergoes less erosion during these events. The nearshore bathymetry in the cove acts to create an east-northeast current, even under the influence of northeasterly winds, and hence sediment does not accumulate on this shore.

In contrast, the western side of the cove is exposed to northeast winds. The community of Grates Cove is located in this zone, developed on less steeply inclined slopes, and colluviated glacigenic diamicton is present inland. As a result, granules, pebbles, and fine cobbles are regularly supplied to the shore. Where not disturbed by anthropogenic activity, this gravel accumulates, forming beaches. The horseshoe configuration of Grates Cove precludes all but east-northeast winds from striking the western shoreline, allowing the gravel to remain. Storm events which do result in the removal of gravel eastward along the shore also increase erosion in the terrestrial areas, allowing subsequent re-supply to the beach systems.

A second example of a Class 5 shoreline is located at Kingston (Heart's Content map sheet, tape reference 1887-1900). Here, transitory beaches composed primarily of coarse pebbles are developed at the base of steep cliffs and over narrow rock platforms of sandstone beds associated with the latest Precambrian Mistaken Point and Trepassey Formations. Slope angles on the beaches generally approximate 20°. The beaches are most susceptible to alteration during northeasterly storm events, which tend to move sediment landward against the cliffs and southwestward along the shoreline, causing the beaches to become steeper and narrower. During late spring, ice shove activity also contributes to creating narrower, more steeply sloping beaches, with angles temporarily exceeding the critical angle of repose. Locally, beach sediment may be completely removed, exposing bare rock platforms, while newer beaches develop to the southwest. Although the beaches are constantly subject to sediment transport to the southwest, replenishment from frost wedging of the cliffs and platforms and from southwesterly transport from adjacent Small Point act to rebuild the beaches after each major storm event. Along this shoreline, rebuilding generally occurs throughout the summer and early fall; maximum reworking is associated with the autumn equinoxial gale season.

Class 5 shorelines are also located at Long Beach, Collier's Point (Harbour Grace map sheet, tape reference 4095; Illustration 5), where they are associated with a narrow rock platform developed on clastic sedimentary rock of the Drook Formation. Aerial photograph analysis of this area indicates that the pebble-dominated character of these beaches has remained consistent since 1966. The sediments at this location are exposed to waves from the east, north, and west, and thus the beaches

are consistently reworked and are subject to energy levels which show less variability than those at Kingston or Grates Cove. Seasonal ice shove is not an effective agent of remobilization at this location.

CLASS 6 -- GRAVEL BEACH WITH ROCK CLIFF

Class 6 shorelines are defined as those with small, fringing, steeply sloping gravel beaches backed by rock cliffs. Frequently, the beaches are also flanked by rock cliffs, and are developed in small coves or clefts in the rock. These are generally referred to as "pocket beaches".

Pocket beaches are common along shorelines dominated by rock cliffs, such as those which mark the Avalon Peninsula. They represent the accumulation areas for sediment derived from local frost wedging and other erosive processes of the rocks surrounding the cove, as well as areas where coarse sediment transported by wave and storm activity accumulates. Along the Conception Bay shore, pocket beaches range in length from less than 10 metres (in areas where narrow, steeply-dipping fractures, faults, or thin shale beds reach sea level) to 10's of metres (where the beaches are developed in small coves). Steep gravel beaches in excess of 100 m in length are assigned to shore Class 15 in this report. In plan view, most pocket beaches have a gently to sharply concave sea front. The width of pocket beaches varies from less than 1 metre to approximately 10 m. Widths tend to vary along the longer pocket beaches, with the greatest widths associated either with an area of stream discharge or on the downcurrent sides of the larger coves.

Healy's Cove (Holyrood map sheet, tape reference 4688) is a typical example of a short, narrow beach formed at the base of a steep slope, where there is no significant channelized stream flow from land. The active part of the beach is approximately 15 m long, and is marked by a gently concave surface profile with a maximum slope of 32° aligned normal to the trend of the beach front. Sediment texture ranges from fine pebbles to medium cobbles. At Healy's Cove, the sediment is derived from terrestrial downslope movement from the diamicton which mantles the slope. Clast shapes and sizes reflect those of the diamicton, as is common where diamicton cliffs provide abundant sediment influx under moderate energy conditions (Jones *et al.* 1995).

At the adjacent site of Ship Cove, 150 m to the northeast, all of the sediment is derived from mass movements from the sandstone bedrock cliffs. Here, the clast characteristics and geomorphology represent those of a terrestrially-derived talus cone.

The Class 6 shoreline at Hibb's Cove (Harbour Grace map sheet, tape reference 3043-3045) represents a different style of pocket beach. At Hibb's Cove, shale of the Fermeuse Formation crops out as a series of low cliffs on the seaward (northeastern) sides of roches moutonées modified by glacial activity during the Late Wisconsinan. Quartz veins within the shale provide additional strength to the rock, and also serve to focus erosion and frost wedging along their margins. Consequently, the beach receives a constant supply of discose shale medium and coarse pebbles, with rare spherical or elongated quartz clasts. No rivers are present, and the configuration of the shoreline effectively

precludes influx of marine sediment through longshore transport. The beach thus develops in isolation from activity elsewhere along the Conception Bay coast.

The beach is marked by a gently concave profile, with a maximum slope angle of 20°. The pebbles form well-oriented assemblages, imbricated with a modal angle of 12° seaward on the upper portion of the beach and $\leq 3°$ seaward at the high tide line, in shingled layers bounded by concave erosional surfaces. Cuspate structures are not present. Storm reworking is generally minimal, and the texture of the beach sediments appears to have remained constant.

A different style of pocket beach develops where cliffs enclose a narrow cove marked by a stream outlet. Shoe Cove (St. John's map sheet, tape reference 5650) is an example of this type of Class 6 shoreline (Illustration 6). The stream influx contributes more texturally varied sediment to the beach system, although gravel deposits comprise > 90 % of the total. The beach profile varies seasonally, from planar in the late spring and early summer, to slightly to strongly concave in mid- to late autumn. Maximum slopes on this fine pebble/coarse cobble beach reach 30°, and are aligned facing northeast, slightly oblique to the beach front.

Modification of the beach system proceeds on a very sporadic basis, with long periods of quiescence separated by extreme reworking episodes associated with the strongest northeastward winds. During late August - early October 1992, a period marked by exceptional northeast gales, the beach was completely reworked into a strongly concave profile, with the most extensive erosion occurring at the southern end. Subsequently, the beach was gradually rebuilt, becoming wider, lower, and more planar in profile throughout 1993 and most of 1994. Northeast gales in autumn 1994 eroded the profile to a concave form, but the absence of comparable events in 1995 have enabled a more planar morphology to dominate again.

Class 6 shorelines with finer gravel textures, locally or temporally alternating with mixed gravel-sand beaches of Class 9, are associated with areas where the cliffs are less enclosing or the cove is less embayed. Such beaches usually are fed in part by streams, and hence have a more texturally varied sediment supply. The sediment texture of these beaches tends to be finer than that of the tightly enclosed pocket beaches. The slopes are slightly concave and gentle, with maxima ranging from 10 - 15° for pebble beaches. Weakly developed cuspate structures are present during the spring and summer months. Gallows Cove, north of Harbour Main (Holyrood map sheet, tape reference 4493-4498) is typical of this style of Class 6 shoreline.

Fringing Class 6 gravel shorelines, where rock cliffs back the shore but do not confine the sediment laterally, are present along the southern side of Bell Island. These shores develop on a temporary basis where sediment supply from the bluffs exceeds the ability of waves and currents to rework and remove it, and the erosional processes involved may be exclusively terrestrial (Nott 1990). The sediment is dominantly or exclusively terrestrial in origin, and is commonly angular to sub-angular and unsorted. The material accumulates at the base of the cliff in a talus apron or cone, and remains until it is reworked by a major storm event. Consequently, these shoreline deposits are not true marine 'beaches'. These features tend to be steep (slope angles locally exceed 40°), narrow, and unstable, and frequently undergo complete or severe degradation during storm events. Along Bell

Island, however, removal of the sediment at the base of the talus apron during a storm often coincides with input of new material from the cliff above, generated by loosening of susceptible, frost-disturbed debris. Thus the events which cause sediment degradation are also largely responsible for replenishment.

CLASS 8 -- SAND & GRAVEL BEACH ON NARROW ROCK PLATFORM

Class 8 beaches resemble those of Class 7, except that they are developed on narrow rock platforms with gentle to moderate slopes. Seasonal or yearly variations in texture may cause these beaches to be classified as gravel systems (Class 5) under some circumstances. Typical examples occur at Spout Cove (Heart's Content map sheet, tape reference 1905; Illustrartion 8), Bradley's Cove (Heart's Content map sheet, tape reference 1816-1818), Biscayan Cove (Pouch Cove map sheet, tape reference 5585-5591), and Bacon Cove (tape reference 4129).

The Class 8 beach at Bacon Cove is composed primarily of fine to medium discoid pebbles. Approximate sand concentrations vary seasonally and yearly between 20 % and 40 %, with the coarsest conditions characteristic of mid-late autumn and early spring. Minor amounts of coarse pebbles and cobbles are also present throughout the year. Sand clasts are derived from the diamicton exposed along the shoreline and overlying the Cambrian sandstone and conglomerate, from erosion of the Cambrian rocks, and from longshore transport from the north.

The beach slope is concave, with the steepest angles of 25° - 30° developed in the autumn and directed towards the east and northeast. Bacon Cove is directly open to winds from this quadrant. Asymmetrical cuspate structures indicate that longshore transport towards the south and southeast also remobilizes the discoid pebbles. Pebble fabric patterns suggest that the clasts are predominantly moved by longshore transport during the summer, whereas shore-normal transport associated with northeast winds is most effective in the autumn.

CLASS 9 -- SAND & GRAVEL BEACH WITH ROCK CLIFF

Class 9 beaches differ from those of Class 6 by containing substantial quantities of sand, between 30% - 70%. Lengths and widths are generally similar to those of Class 6, and these beaches can also be considered as "pocket beaches". Steep mixed sediment beaches in excess of 100 m in length are assigned to shore Class 18 in this report.

Mixed sediment beaches develop at the base of steep cliffs where frostwedged clasts (which are generally coarse gravels) are joined by fine gravel and sand derived from other sources. Along the Conception Bay shoreline, sand originates from Quaternary glaciofluvial units, glacigenic and colluvial diamictons, bluffs of Quaternary deposits up-current that are prone to slope failure, and from focusing of deposition of sand derived from distal upcurrent locations or from nearby offshore sources. The variety of bedrock units which crop out along the shoreline, and the mineralogy of the

glaciofluvial and diamicton deposits derived from them, allows the provenance and transport direction of coarse sands and fine gravels to be determined in some instances.

The generally thin and discontinuous Quaternary sediment cover, especially in coastal regions, limits the formation of Class 9 shorelines, and as a result these are much less common than the coarser pocket beaches of Class 6. All examples in the study area have gravel contents in excess of sand. The surface profiles are moderately to strongly concave, and maximum slopes vary between 15° and 25°, with steeper slopes associated with lower sand contents (± 15-20 %). Cuspate features develop very rarely, and when produced are highly ephemeral. The steepest slopes are aligned at sharply acute angles (60°- 90°) to the trend of the beach front. Divergence of slopes along the shoreline is rare, in contrast to the marked divergence evident on several gravel pocket beaches.

Storm reworking results in temporary modification of these beaches, but the changes do not appear to be long-lasting. Coarse pebbles and cobbles are frequently exhumed by storms, but rapid re-burial by sand, granules, and fine pebbles commonly occurs. Coves which are confined by headlands, especially on the southern side, are marked by cyclical movement of the sand fraction, with sand being swept offshore during backwash from storm surges and then returning to the beach subsequently. These beaches, such as Jugglers Cove (Harbour Grace map sheet, tape reference 2531; Illustration 9) thus will appear to maintain a relatively consistent texture, unless they are photographed or visited within approximately 2 - 4 weeks of a major storm. In contrast, coves which are less confined or unconfined are marked by substantial longshore movement of sand, and consequently show variations in texture with temporally shifting wind directions. Examples of this type of Class 9 shoreline include Bishops Cove (Harbour Grace map sheet, tape reference 2362), and Freshwater Cove, Bell Island.

Jugglers Cove is the site of an abandoned settlement northeast of Bay Roberts. During the period of human occupation, shoreline modification and land clearance resulted in the production of enhanced amounts of sand. This material has been washed downslope into the cove, where it has remained trapped by a submarine bedrock ridge. The cove is open to the southeast, and thus is sheltered from the full effects of northeast winds. Consequently, although the sand is moved alternately away from and towards the shoreline it has remained in the cove, contributing to the beach morphology.

CLASS 10 -- SAND BEACH ON WIDE ROCK PLATFORM

The only areas along the Conception Bay shore that have beaches with sand concentrations in excess of 70 % are located at Northern Bay Sands and Salmon Cove. The lithology of the bedrock units, the prevalence of frost weathering, the scarcity of fine-grained Quaternary sedimentary deposits onshore, the steep slopes, and the high energy environments characteristic of much of the shoreline effectively limit the opportunities for developing sandy beaches. These factors are especially evident in locations where the bedrock comprises a substantial element of the shoreline. Consequently, no examples of sand beaches associated with wide rock platforms are present in the study region.

CLASS 11 -- SAND BEACH ON NARROW ROCK PLATFORM
CLASS 12 -- SAND BEACH WITH ROCK CLIFF

Class 11 beaches differ from those of Class 10 in that they are developed on narrow rock platforms. The only example of a Class 11 shoreline in the region is present at Northern Bay Sands (Illustration 10). Class 12 shorelines, sand beaches backed by rock cliffs, are also uncommon along the Conception Bay shoreline, being confined to only two localities: Northern Bay Sands (tape reference 1710-1735; Illustration 11), and Salmon Cove (1932-1945). Both of these localities are also associated with the only sand flats (shore Classes 19 and 20) present in the study region. Northern Bay Sands and Salmon Cove differ substantially, however, in terms of geomorphic setting, sediment supply, and coastal development. As Northern Bay Sands is marked by sand input from bedrock sources, both adjacent and distal, it will be discussed here.

As an exposed sandy beach not backed by significant aeolian dunes, Northern Bay Sands is unique among Avalon Peninsula shorelines. The sandy shoreline is gently concave in plan view, extends for 750 metres, and has a maximum width of 110 metres. The texture of the beach is controlled by shore-parallel transport in a southerly direction. During the late autumn and late spring, following the breakup of the seasonal ice foot, the beach generally fines from granules in the north to fine-medium sand in the south. The system is characteristically drift-aligned, marked by longshore migration from north to south. Interference by edge wave development alters the pattern of longshore transport when southeasterly winds are dominant, and segments of the beach show transitory swash-aligned features under these circumstances.

The beach is backed by bedrock cliffs at both its northern and southern margins, which contribute some sand and granules to the system. Sand input also comes from the glacigenic sediment bluffs which back the central and southern segments of the shoreline. This material is transported seaward by fast-flowing shallow, somewhat ephemeral streams characterised by seasonal development of antidunes. Recently, additional sediment input has resulted as a consequence of anthropogenic disturbance of areas extending north to Caplin Cove, as a result of dredging and littoral construction. Sheep rearing has increased throughout the region following the imposition of the Northern Cod Moratorium in 1992, resulting in increased erosion of coastal sediment exposures and increased input of sand to the coastal drift. The sand influx has resulted in a general textural fining along all the sand-containing systems of the Conception Bay coastline, and in increases in the proportion of sand in systems with mixed sediment.

Study of Northern Bay Sands is difficult during the short tourist season (July-early September in most years), as this shoreline receives a substantial number of visitors. During hot summers (such as those of 1990, 1991, and 1995), more than 20,000 people are estimated to visit the beach, effectively destroying all natural features in the central, most heavily-utilized area (shore Class 19). In more moderate (1994) and substantially cooler years (1992 and 1993), visitation is significantly reduced, allowing study of the summer development of the beach profiles. Few visitors frequent the area between mid-September and mid-June.

Summer and early fall profiles in undisturbed areas are very gently concave to planar, with slopes of <1° to 3°. During late fall, the beach front is steepened through erosion by south-flowing shore-parallel currents, reaching a maximum slope of 6° and developing irregularly alternating convex-concave profiles in the intertidal and lower supratidal areas. Northeast storms accentuate the longshore tendency, accelerating profile modification but leaving the shoreline configuration unaltered. On rare occasions when southeast winds are significant (as in November 1994), the shore is eroded by shore-normal waves, and a temporary steep beach front with slopes to 10° develops. These slopes, however, are rapidly modified and lowered when the longshore currents are re-established and drift alignment dominates.

An ice foot develops in late December-early January, and reaches a thickness of 60-70 cm by late March or early April. Ice foot development has occurred in every winter from 1989-90 to 1994-95, and in 1996-97. Recently, ice foot development has not occurred during the winters of 1995-96, 1997-98, and 1998-99. During the winter months, virtually no sedimentary activity occurs on the system, except for minor niveo-aeolian reworking of the backbeach areas. The spring profile thus reflects the conditions of late autumn. Modification proceeds throughout late April, May, and early June, by which time the essentially planar surface profile has become re-established.

Northern Bay Sands exhibits both periods marked by dissipative conditions, and periods where reflective conditions are dominant. Shore-parallel and shore-normal transport both occur in association with temporary reflective and dissipative regimes. These fluctuations result in sedimentary features which are transitory and highly ephemeral, and contribute to the general featurelessness of many parts of the beach (even in undisturbed areas). Subaqueous ripples are characteristically straight-crested with low sinuosity, and have ripple indices ranging from 3 to 8 (cf. Tanner 1967). Aeolian ripples and adhesion structures are also common. Cuspate structures are very rarely developed. Swash /backwash angles on the beach range between 60° and 150°, the high degree of variation reflecting the sporadic shifting between shore-normal and shore-parallel transport modes.

Despite the relatively high rate of visitation (by Newfoundland standards), the anthropogenic impact on Northern Bay Sands has been much less than at other Avalon localities such as Topsail Beach and Salmon Cove (as discussed in this report). The exposed nature of the beach and the strong component of shore-parallel transport allows constant replenishment of the sands of the beach system. There are no significant impediments to transport to the north of the sands. Anthropogenic disturbance has increased erosion of more northerly areas, resulting in an enhanced sediment influx to Northern Bay.

CLASS 13 -- WIDE GRAVEL FLAT

Class 13 shores are defined as those with gravel-dominated flats (less than 30% sand component) which have maximum widths in excess of 30 m. Along the Conception Bay coast, most Class 13 shores contain less than 10 % sand-sized particles, and widths rarely exceed 50 m. Wide gravel flat areas are associated with many communities with historical roots in the fishery, although some are

not currently marked by activity. Anthropogenic modification of the shorelines began upon occupation, and has continued to the present.

Although these communities were initially established because the gravel flats were suitable areas for processing fish for export, aspect also played an important role along the Conception Bay shore. Communities were generally built on the north side (south-facing side) of embayments where possible. These slopes received less snow and were less subject to frost heave and freezing rain than the north-facing slopes, and hence were more suitable for fish processing and building construction. In addition, the circulation pattern in most embayments is marked by marine water influx along the northern shoreline, in part due to Coriolis effects and in part due to the dominant north-south motion of the longshore current. Consequently, access to the north side of the harbours was easier for incoming vessels, and outbound vessels had a favourable current along the southern shoreline. Currents also acted to sweep the harbour areas on the northern sides clear of sediment, and deposited it preferentially on the southern sides of the embayment heads and on the southern shorelines. Thus, the sediments tended to accumulate preferentially on the southern sides of the embayments, a pattern which persists today.

The Class 13 shores vary substantially in sediment texture, small- and large-scale sedimentary structures, overall morphology, and genesis. Textural assemblages range across the entire spectrum of gravel deposits. Boulder and coarse cobble-dominated assemblages represent combinations of essentially relict sedimentary deposits formed during deglaciation with material deliberately added to the shoreline during railroad and road construction (parts of Clarke's Beach and Spaniard's Bay assemblages, tape references 3235-3306 and 2390-2403, respectively). Unaltered boulder-dominated assemblages, such as that at Big Barasway on Placentia Bay (Boger 1994, Catto *et al.* in press) are not present along Conception Bay. Other assemblages which are seasonally dominated by fine pebbles and granules during relatively low energy late summer months, such as King's Beach, Harbour Grace (tape reference 2172-2178), are marked by coarse pebbles and cobbles under different wind and wave patterns and energy conditions. Sorting varies from very good to moderately poor and seasonal shifts in texture are ubiquitous throughout the Conception Bay shoreline on Class 13 systems. Even in those areas with extensive anthropogenic modification, seasonal and locally diurnal changes in the intertidal and subtidal areas are apparent. Individual segments of complex, lengthy beaches show differing patterns of textural variation along their lengths, both seasonally and in response to individual storm events. Beaches also differ in texture depending on the style of sediment transportation (shore-parallel, shore-normal, or oblique), and on the relative strength and consistency of seaward sediment movement. Similar variations have been recorded on other gravel and sand beaches subject to differing energy levels (e.g. Carr *et al.* 1982, Dubois 1989, Miller *et al.* 1989, Héquette and Ruz 1990, Jennings and Smyth 1990, Thorn and Wall 1991, Medina *et al.* 1994).

Sedimentary structures, both small- and large-scale, show spatial and temporal variability. Most beaches are too coarse to permit the formation of ripples, and the development of small-scale sedimentary structures is confined to short periods of relative quiescence. Swash and backwash bar complexes, small cuspate features, and viscous grain flow cones, fans, and sheets mark pebble-dominated beaches during the early summer months. Such features are ephemeral, being destroyed and re-formed on a daily basis. In years marked by autumn storms accompanied by northeast winds

(eg. 1992, 1994), none of these features survive intense reworking. In autumns without strong northeasterly gales (eg. 1993, 1995), many features do survive in a modified form throughout the winter, although all shorelines along the central and northern Conception Bay coast are subject to ice foot development.

The Class 13 shoreline along the Spaniard's Bay coast northwest of Bay Roberts (tape reference 2407-2433) is marked by cuspate development during the summer and autumn. Cusps characteristically have breadths (along shore) of 2 - 5 m (greatest in 1992; least in 1993), widths (normal to shore) of 1-1.5 m (little variation between 1992 and 1995), and depths of 0.3 - 1.3 m (greatest in 1994, least in 1992). These cusps are moderate in size in comparison to those formed elsewhere along the Conception Bay shoreline and along Placentia Bay (Catto *et al.* in press). The cusps are symmetrical about their central axes, and are oriented consistently towards the northeast. The breadths are thus aligned slightly oblique (azimuth deviation 10-15°) to the trend of the beach front. Slope angles along the cusp back walls, along the central axes, range from minimum values of 8° to maxima of 41°. The lowest slopes were recorded following overwashing associated with the severe northeast storms of October 1992. Higher slope angles are more characteristic of the cusp forms from late summer to late autumn, especially in years where storm overwashing has not occurred (e.g. 1993, 1995). During these years, maximum slope angles typically range between 25° and 35°.

The shoreline is dominated by coarse pebbles and cobbles throughout the year, although the proportion of cobbles on the surface increases following major storms. Pebbles and cobbles move downslope by viscous grain flow and by collapse of oversteepened cusps between major storm events, often forming temporary sheets, cones, and fans of sorted material with the coarsest clasts at the base. Weakly developed shore-parallel bars composed of pebbles are occasionally present in the nearshore areas, with heights of 10-20 cm, widths of 30-70 cm, and lengths to 3 m. These bars are generally linear in configuration, and are very ephemeral, being evident only following major northeast storm events.

The shoreline of Spaniard's Bay is marked by moderate to high energy conditions throughout the year. Except when ice foot development precludes sediment reworking, pebbles and cobbles are moved onshore by waves and return offshore by backwash and sediment gravity flows (viscous grain flows). The energy is expended in the offshore and beach front areas, and little outward flow is present. Structures and clast fabric patterns indicate that the beach is reflective and swash-dominated.

A Class 13 shoreline developed under different environmental conditions is present along the northwestern segment of Clarke's Beach (Illustration 12). This area is dominated by pebbles, with lesser amounts of sand (varying seasonally from 5-20 %) and cobbles (± 5 %). Cuspate structures are present throughout the summer and autumn, and are generally wider (0.7-2 m) than broad (0.5 - 1.5 m). These cusps thus form a series of chute-like features aligned approximately normal to the shoreline, although the axial orientations vary seasonally and throughout the length of this part of the beach. Axial orientations range from east-southeast, deviating eastward by approximately 45° from the northwest-southeast trend of the shoreline, to due north. The axes of the cusps reflect the dominant angles of attack of the waves responsible for their formation. Although many deviations

exist, the cusps associated with the northwesternmost part of the beach at low elevations (< 2 m asl) are most likely to be aligned towards the southeast. Cusps on the southernmost part of this shore, and those with bases more than 2 m asl, are more likely to be aligned to face the northeast or east-northeast. Cusps facing north are confined to low elevations at the southern end of the system. All of the cusps are shallow, with depths seldom exceeding 0.5 m. Slope angles are low, with maximum values ranging from 8° -22°. The cusps are slightly asymmetrical in plan view, with the degree of asymmetry reflecting the obliquity of wave approach with respect to the shore face orientation.

In addition to the cusps, obliquely-aligned offshore and nearshore bars composed of medium-coarse pebbles are present. The bars are generally crescentic in plan view, concave with respect to the shoreline, with short, weakly-defined horns pointing shoreward. They range from 0.7-2 m in length, 10-30 cm in width, and are less than 10 cm high. They are present in intertidal and shallow subtidal areas, and are preserved above sea level where not disturbed by subsequent cusp development. Imbrication and clast fabric patterns suggest that the bars are associated with backwash activity, as sediments are reworked from cusps and moved seaward (Gruszczynski *et al.* 1993). The preservation of these features, albeit on a transitory basis, suggests that 'normal' swash energy levels are insufficient to rapidly remove features created during storm periods marked by strong backwash. Cones and sheets of pebbles produced by viscous grain flows are also present as transitory features.

The northern segment of Clarke's Beach is dominated by shore normal transport, with conditions generally being characterized by moderate to low energy. Occasional high energy events, associated with storm activity, produce significant overwashing along the beach, resulting in the chute-like cusps. Flow in the seaward direction associated with these higher energy events constructs the backwash bars associated with many of the cusps. The area is thus marked by changes in energy level throughout the summer and autumn, and energy levels here are much less consistent than is the case at Spaniard's Bay.

The southern part of Clarke's Beach differs from the northern segment. Such variations occur where aspect influences the wave energies which reach different parts of the system (cf. Finkelstein 1982). Sediment here is generally coarse pebbles and cobbles, suggesting higher energy levels. The southern segment of Clarke's Beach faces the northeast, and thus is directly exposed to the full force of northeasterly gales in the late summer and autumn. During the storms of autumn 1992, this part of the beach was overtopped on several occasions, and marine sediment was transported over the artificial retaining wall and across the highway into the lagoon to the southwest. Under the influence of northeasterly winds, therefore, high energy shore normal transport dominates.

The cuspate structures generally present on this shore, however, indicate that other conditions are more prevalent. One or two tiers of cusps are usually present. Strongly asymmetrical slopes indicate that the dominant direction of transport is towards the southeast, with sediment moving oblique to the shoreline trend at shallow angles (10°-30° azimuth). Where two tiers are present, the upper cusps are larger and less well defined than the lower set, but have similar forms and orientations. The cusps are much broader than wide, with breadths occasionally exceeding 3 m and widths rarely exceeding 30 cm. Depths are comparable to widths, and some examples are deeper than they are wide. Slopes measured parallel to the axes of sediment transport rarely exceed 12°.

These shallow, open structures indicate that longshore transport was dominant over shore normal transport during the period of their formation. Shore-parallel transport is also indicated by the presence of ephemeral small bars and spits, oriented transverse to the shoreline. Towards the northern part of the beach, the cusps display gradual changes in morphology, becoming successively wider, more symmetrical, and open to the northeast. These features are transitional to the cusps produced by shore-normal activity that characterize the northern segment of Clarke's Beach.

The southern part of Clarke's Beach differs from the northern segment because shore-parallel and oblique transport is more important and more consistent along this shoreline. Energy levels are generally higher in the southern segment of the beach. The northern segment is less affected by longshore currents, and is somewhat sheltered from the full effects of northeastern winds. An additional factor at the southern end of Clarke's Beach is the return flow seaward parallel to the southeastern shoreline, coupled with fluvial influx from South River. Prior to construction of the Conception Bay Highway, South River discharged directly into Bay de Grave, eroding the southeastern shoreline and creating a bathymetric low. This acted to funnel the outbound current along the shoreline, accelerating water movement. Construction of the modern highway and associated shoreline protective measures have diminished the effect of discharge of South River, as has the development of the aggregate pits upstream and other modifications in land use practices. Consequently, the bathymetric low is likely to gradually become infilled with sediment, reducing the return northeastward flow to Bay de Grave. Eventually, this may alter the southern part of the Clarke's Beach system, causing shore normal transport to gain in relative importance.

King's Beach, Harbour Grace (tape reference 2172-2178) is another example of a Class 13 shoreline. King's Beach is a recurved spit, oriented approximately parallel to the shoreline, that has remained a prominent coastal feature for at least 200 years (it is present on all examined maps of the Harbour Grace area). The fine pebbles and granules which dominate indicate that this shore in general is subject to lower energy levels than are Bay Roberts or Clarke's Beach. The orientation of the spit, as well as the presence of transitory shore-normal bars and spits, suggests that shore parallel transport dominates on a consistent basis. The orientation and development of the spit also indicates the absence of significant tidal influx (cf. Tessler and de Mahiques 1993). Cuspate structures are rare, and when present are small, with breadths < 1 m, widths < 0.5 m, and depths < 30 cm. Maximum slopes do not exceed 15°, and most slopes are < 5°. The cusps are strongly asymmetrical, and show a variety of axial orientations suggesting variations in the obliquity of the angles of wave attack. The shoreline is dominated by imbricated sheets of pebbles, inclined normal to the longshore current direction, that generally slope at < 5°.

As a result of its stability and lower energy levels, King's Beach has long been a favourite area for landing small boats and for inspecting fishing gear, as well as for other recreational activities. These activities result in disturbance to the natural beach morphology and pebble alignments, increasing the flatness and featurelessness of the shore. The morphology of the system can best be observed immediately following a storm, but even major events (such as those of autumn 1992) effect relatively little change to the system. The apparent low energy regime of King's Beach thus can be assumed to represent its actual condition.

The configuration of the flat, as an attached spit oriented oblique to the shore midway along a major embayment, is unique to the Conception Bay region. The stability of the spit is also somewhat unusual and unexpected, as the geological structure is aligned parallel to the Harbour Grace embayment. King's Beach appears to have developed on the flank of a ridge or fan of glacigenic sediment, possibly a fan delta built into Harbour Grace at the conclusion of the Late Wisconsinan glaciation.

The degrees of variation between the shorelines grouped together within Class 13, and the spatial and temporal variations within individual Class 13 systems, are therefore considerable. Generalizing among Class 13 systems is difficult, and a thoroughly comprehensive approach would necessitate monitoring individual beaches over a period of several years. Similar variations have been recorded in gravel systems in many other areas (Finkelstein 1982, Carter *et al.* 1989, Duffy *et al.* 1989, Forbes *et al.* 1991, Medina *et al.* 1994).

CLASS 14 -- NARROW GRAVEL FLAT

Class 14 shorelines differ from Class 13 in that the width of the gravel flat is less than 30 m. These shores can develop where steep bathymetry precludes the genesis of a Class 13 shore, or where a bluff of Quaternary sediment provides an ample source of coarse material along a relatively straight, non-embayed, segment of coastline. At Holyrood beach, the former railway embankment results in a similar effect. The embankment acts as a back berm for the beach, providing coarse sediment and serving as a framework element controlling onshore sediment movement and providing stability to the beach system. Textural variation within Class 14 shorelines is considerable, with shorelines dominated by most grades of gravel, from granules to fine boulders. Most Class 14 shores along Conception Bay are composed predominantly of coarse pebbles and cobbles. Sedimentary structures resemble those of the wider gravel flats. Typical examples are located at Grates Cove (tape reference 1300-1305) and Easter Beach, Kelly's Island (not shown on tape).

Holyrood beach (tape reference 4805-4845) is a good example of this class of shoreline (Illustration 13). The beach profile varies from gently sloping planar (modal 4°) extending across the entire breadth of the system (after maximum summer deposition in 1993) to strongly concave, with some slope angles in excess of 35° (after the storms of October 1992), to weakly convex with nearshore shores reaching 18° (late autumn 1994). Cuspate structures are present, and vary in character along the breadth of the system. At the northwestern end, cusps tend to be shallow, with breadth in excess of width, suggesting that longshore transport towards the southeast is the most persistent process. In the central part of the beach, the cusps are less persistent, and vary from well-defined large, circular, steeply sloping features with seaward lips to poorly-defined small, asymmetrical, shallow excavations. Here, longshore transport (towards the southeast) is associated with quiescent periods, whereas shore-normal transport (from the northeast) is also significant. Severe storms cause the development of larger cusps, but the forms are modified and flattened as a result of seaward flow reflected by the railway embankment. In the southern part of Holyrood beach, cusps are rare and when present are poorly defined features associated with oblique flow towards the east and northeast, along the shoreline.

The shore at Easter Beach, Kelly's Island, is also representative of this class. Here, the coastline is exposed to waves from both southwest and northeast. The cuspate spit developed is thus fed by waves of differing energies, producing textural and morphological differences on each linear segment. Changes in energy will result in substantial modification of the spit, with northeasterly winds steepening and coarsening the northern side and southwesterly winds similarly modifying the southwestern side. The greater fetch to the northeast, and the strength of the northeasterly gales, has resulted in the northeastern side becoming generally coarser and steeper than the southwestern side, although observations of the beach after individual storms produce widely differing results. The modal texture of the shore varies from fine to coarse pebbles, and the slope angles range from <5° to >35°. Cuspate structures are infrequently present along the northeastern side of the spit. Along the southwestern side, cusps are more common, and generally have breadths greater than widths, gentle slopes, and shallow depths, indicating shore-parallel transport parallel to the axis of the Bell Island Tickle.

CLASS 15 -- STEEP GRAVEL BEACH

Steep gravel beaches commonly exhibit a wide range of texture and morphology from season to season, and among locations. As discussed above, transitional assemblages are very common throughout the Conception Bay region. Textures on Class 15 beaches range from granules to boulders, but coarse pebble-dominated systems are most common along Conception Bay. Seasonal and/or yearly variations in classification between gravel and sand-and-gravel beaches occur in some areas. The Class 15 shorelines in the study region can be divided into two categories: those marked by high-energy conditions throughout most of the year, and those where lower energies generally prevail.

High Energy Class 15 Shorelines

High energy class 15 shores are usually reflective in nature throughout the year, although shorter periods of dissipative behaviour are evident at some locations. These shorelines are dominated by shore-normal transport and swash-aligned features, although shore-parallel and oblique transport also occurs locally. These high energy cove systems are developed along indented or embayed coastlines marked by deep bathymetry, which are aligned facing the prevailing (or storm) winds and waves. These coves may undergo intense modification during storm events, followed by long periods of quiescence. Although the effect of any particular storm will vary depending upon its azimuth orientation, the most severely (and consistently) affected coves are those which face northeastward towards the open waters of Conception Bay, such as Bristol's Hope and Bryant's Cove.

The beach at Bristol's Hope (tape reference 2082-2096) represents an excellent example of a Class 15 high-energy cove (Illustration 14). The cove faces northeastward, directly fronting the prevailing wind direction, and is exposed to all waves generated by northeasterly winds. During the autumnal gale season, the cove is strongly affected by any and all storms. The severe storms which marked late September and early October 1992 had a major effect on Bristol's Hope. As the storms of 1993 were

less potent, the structures created by the 1992 storms remained intact until high energy events in summer 1994, which caused modifications to the lower parts of the beach but left the uppermost areas intact. The 1992 storm features thus escaped modification, and probably would have persisted until the next comparable storm. In other, less frequently storm-influenced coves (such as Witless Bay and Brigus South, on the Southern Shore), storm features created by a major storm event in 1966 are still visible. The features at Bristol's Hope, however, were destroyed in the process of the reconstruction of the beachfront road in 1994 and 1995, an event which substantially altered the entire system.

The beach at Bristol's Hope shows a gradual transition along its 280 metre, gently concave length. The southeastern margin is most exposed to shore normal transport induced by northeasterly winds and waves, and prior to 1995 was marked by strongly concave profiles with several tiers of stacked gravel cusps. Storm waves led to the formation of cuspate structures on the beach, causing temporary irregularities in the profiles. The resulting profiles were made up of several superimposed concave cusps, giving a somewhat scalloped appearance to the overall concave shape. These irregularities persisted until the next major storm. In early September 1992, prior to the severe autumn storms, six tiers of gravel cusps were evident. Following the storm event, all of the cusps were destroyed, save for the uppermost structures created by the storm waves, 6-7 metres above mean sea level. Lower tiers of cusps were gradually rebuilt by lesser energy waves, and four tiers existed in spring and early summer 1994.

Following road construction, only the two lowest tiers of cusps remained. Northeast winds during the autumn of 1995 were weaker than in any of the previous 4 years, precluding the re-formation of the upper tiers of cusps. In December 1995, two tiers were evident along most of the southeastern margin, with a third intermediate tier present at the southeastern most edge of the system.

The northwestern margin is most sheltered from direct impact of the storm waves but formerly received a substantial amount of material transported parallel and oblique to the shore from the high energy southern area during storm events. Along this segment of the beach, the net effect of storm activity was accretion, as sediment from the length of the shoreline was focused in the northwestern area. Stacked tiers of gravel cusps formed ramparts in this area, but the ramparts were generally lower (4 metres asl) and fewer tiers were evident. The orientation of the cusps indicated that shore-parallel and shore-normal transport were both involved in their formation, in contrast to the exclusively shore-normal patterns evident in the southern part of the system. The fishing stage at Bristol's Hope, damaged in the 1992 storm, was located at the far northern end of the beach, within the zone marked by the lowest possible energy regime.

Road construction resulted in a reduction of the sediment available for re-mobilization by storm waves. As no major northeast storms occurred in the autumn of 1995, the effect of reduced sediment supply on the geomorphology of the northern segment has not yet become evident. The road building, however, has lowered the crest height of the beach along its entire length, which will act to facilitate overwash of the beach during the next major storm. In addition to destroying the road, increased overwash activity and shore-normal transport will result in the infilling of the lagoon behind the beach, causing sediment to move inland rather than along the shore. Further storms would serve

to accentuate this trend. The net result over time is likely to be a continued flattening of the beach crest, exposing the lagoon and terrain behind to storm wave activity, while inducing further erosion of the now sediment-starved northern segment.

The cusps that have developed along the southeastern and northwestern segments of the beach show morphological differences. These differences reflect differing wave energy conditions, durations of wave events, the relative importance of onshore-offshore transport versus shore parallel transport, and the relative energies and erosive strengths of the incoming and outgoing water. Along the southeastern margin, the hollows between the gravel cusps along the uppermost rampart were elongate, linear depressions, with breadths less than widths, that gradually sloped landward at 3° - 8°. These depressions were open on the seaward side, rather than being bordered by a seaward lip as is common elsewhere along the shoreline. These structures were produced during the height of the 1992 storm by washover events, as waves overtopped the barrier and dispersed landward.

The overall configuration of the hollows between the gravel cusps developed on the lower tiers of the southeastern segment prior to road construction, and those forms developing at present, is essentially circular in plan view, with a deep central depression, steep back slopes, and a lip at the seaward edge. These circular structures with strongly concave cross-sections represent dominant onshore-offshore movement of water and sediment. The cusps are formed by waves which strike the shore parallel to its trend. At the southeasternmost margin, where shore-parallel transport of sediment is negligible, the slopes bordering the depressions are symmetrical and have similar angles with respect to the trend of the shoreline. Towards the central point of the beach, the depression and slopes are asymmetrical, with the degree of skewness reflecting the oblique angle of wave attack on the shore and the impact of shore-parallel transport.

Along the northwestern segment of the beach, the cusp hollows are shallow, with widths less than breadths, and with weakly developed or no seaward lips. These cusps are formed by shore-parallel transport from the southeast, combined with shore-normal transport from the northwest, and hence are intermediate in form and subject to sporadic modification. The asymmetrical nature of the structures associated with the uppermost tiers indicates that shore-parallel transport was dominant during high-energy events, reflecting the swash-backwash pattern associated with major storms. In contrast, the lower tiers of cusps are generally more symmetrical and have better-developed seaward lips, indicating that under 'normal' conditions, shore-normal transport dominates in the northwestern segment of the cove.

Bryant's Cove (tape reference 2299-2305) is currently the subject of additional research. It is less embayed and more exposed to wave attack than is Bristol's Hope, and consequently shore parallel (northwest-southeast) and shore oblique transport are of substantial importance. Shore normal transport and reflective conditions, however, appear to be the dominant mode. Cusps are present in one to three stacked tiers, and are generally symmetrical bowls, with seaward lips and back slopes in excess of 30°. The beach is dominated by coarse pebbles.

The more open nature of the coastline does not permit wave energy to be focused as effectively as at Bristol's Hope. Thus, Bryant's Cove is subjected to generally higher wave energy than is Bristol's

Hope, but individual strong storm events are more likely to be destructive at the latter, as was indicated by the relative effects of the storms of autumn 1992 and autumn 1994.

Moderate to Low Energy Class 15 Shorelines

Moderate to low energy bayhead bars and pocket beaches are common along parts of the Conception Bay shoreline dominated by rock cliffs. They represent the accumulation areas for sediment derived from local frost wedging and other erosive processes of the rocks surrounding the cove, as well as areas where coarse sediment transported by wave and storm activity accumulates. Two typical examples are located at Caplin Cove and Chapel Cove.

The beach at Caplin Cove (tape reference 1550-1562) is 75 metres in length and has a maximum width of 11 metres. The maximum width is developed adjacent to the stream which discharges into the southern side of the embayment, a position which coincides with the downcurrent direction of shore-parallel transport. The sea front is moderately concave in plan view. The cove is backed and flanked by argillite and sandstone bedrock cliffs (Gibbett Hill and Bay de Verde Formations), with a thin cover of coarse Quaternary diamicton, deposited as glacial till and subsequently modified extensively by colluviation. Sediment supply to the beach is provided from the cliffs to the north, and by the stream which is reworking the glacigenic and colluvial sediment throughout the small drainage basin. Little sediment is transported southward from the cove.

Slope angles along Caplin Cove vary with the texture of the sediment and the degree of recent reworking by storm and wave activity. Slope angles are generally directly proportional to the dominant grain size involved. On the narrowest segments formed at the base of the steepest cliffs, where there is no significant channelized stream flow from land, clasts lie at or close to the critical angle of repose for dry sediment. At Caplin Cove, these areas are located along the northern part of the cove, and slope angles range from 30° - 38°. These segments have gently concave surface profiles, with the steepest slopes aligned perpendicular to the trend of the beach front. Accumulation of the sediment proceeds largely by mass movement, and the internal structures of the beach resembles those of terrestrial talus cones.

Storm reworking of these areas is infrequent, and most commonly results in removal of finer pebbles and cobbles, creating instabilities in the beach system and triggering small mass movements on the beach surfaces. These disturbances alter the concave profiles of the beaches, producing temporary surfaces marked by alternating zones of convex and concave slopes. Characteristically, these irregularities are gradually eliminated as further material is provided to the beach, usually within a few weeks if no subsequent storms intervene.

On the southern side of the cove, sediment influx is greater as a result of the net direction of shore-parallel transport and the stream input. Energy levels are more consistent along the southern side of the cove, as this area faces the prevailing winds. Consequently, the sediment is better sorted and dominated by fine to medium pebbles, ideal for capelin spawning. During the summer and early autumn, the beach exhibits a concave profile, with the maximum angles of slope (18°-22°) in the

locations furthest removed from wave and river activity. The pebbles on the beach are imbricated seaward during the early summer, but are disturbed extensively during the capelin spawning season.

Cuspate structures are present during the spring and summer months. The steepest slopes tend to be aligned at sharp acute angles (70° - 75°) to the trend of the beach front, facing the direction of the prevalent waves. Different parts of the beach slope at different angles and trends, indicating differing wave strengths and angles of attack, in consequence of the local bathymetry.

During the equinoxial gale season, the cove is subject to modification by northeasterly wind-driven waves, resulting in erosion of the shoreline along the southern margin and a general steepening of the beach front. Severe storms, such as those which marked the fall of 1992, remove substantial quantities of fine and medium-grained pebbles from the beach front. These clasts, however, are retained in the cove system, and are subsequently redeposited onshore during the spring (following disintegration of the ice foot). Consequently, the beach is rebuilt texturally and geomorphologically prior to the advent of the subsequent capelin spawning season.

Chapel Cove (tape reference 4616-4638) is a Class 15 shoreline marked by low to moderate energy conditions, dominated by medium pebbles. The beach face is a moderate to steeply sloping (14°-27°) system. Profiles are generally planar in the late spring and early summer, gradually becoming concave as material is removed from the lower beach face during the late summer and autumn. Cuspate features form between one and three tiers, with individual cusps varying from 1-2.5 m in breadth, 0.5-1.5 m in width, and 0.3-0.7 m in depth. The cusps modally are slightly broader (parallel to the shore) than wide (normal to the shore), and are slightly asymmetrical in plan view. Cusp orientations and clast fabric patterns indicate that shore normal transport is dominant, and that the beach is reflective. Offshore bars and clast monolayer lines are swash-aligned features.

Unlike Caplin Cove, Chapel Cove has been subject to considerable anthropogenic modification. The beach is backed by a retaining wall, which limits sediment resupply to the system from the land. Access to the lagoon is controlled by an artificially maintained channel at the southeastern end, and the channel is dredged to seaward. The channel has acted to focus wave energy to the southeast side of the beach, accentuating shore normal transport in this area and causing the beach face to steepen. During periods of northeasterly winds, this acts to focus and consequently increase the wave energy affecting the southeastern part of the system, resulting in sediment transport into the artificial channel and the lagoon behind. The channel must thus be re-dredged following each major northeast storm, if access to the harbour in the lagoon is to be maintained.

CLASS 16 -- WIDE GRAVEL & SAND FLAT

Class 16 shorelines are differentiated from those of Class 13 on the basis of texture. A Class 16 shoreline is defined here as a wide flat which contains between 25 % and 70 % sand, as determined either from visual estimates or *in* situ sampling. Class 16 beaches investigated in the Conception Bay region, as exemplified by those at Kelligrews and Chamberlains (tape references 5050-5070; 5138-5168) are generally dominated by fine pebbles and granules. The sand proportion is usually 25-35%,

generally as coarse-grained particles, and is dominantly concentrated in the intertidal and subtidal zones. In many areas, the sand is veneered by fine to medium pebbles, and thus visual inspection without field investigation may lead to an under-estimate of the sand proportion.

Class 16 gravel and sand flats undergo textural modification over time scales from hours to years. Gradations to other shoreline classes of differing slopes, widths, and textures are common. Changes in wind direction, wave energy, and sediment availability are responsible for these textural and morphological variations. Along the Conception Bay South shoreline, changes in anthropogenic activity and coastal land use have also resulted in textural and morphological modifications.

The Class 16 shorelines at Kelligrews (Illustration 15) and Chamberlains are marked by gentle to moderate seaward slopes (2°-11°) throughout the majority of time. Following storm events, however, individual slopes may exceed 25°. The Kelligrews area generally has steeper slopes than does Chamberlains. Cusps associated with non-storm periods, and those developed in association with southwestward winds, are poorly to moderately developed, and have breadths much greater than widths. These cusps are shallow and asymmetrical in plan view, and develop as northeastward-flowing currents strike the coastline at oblique angles ranging from 5° to 35°. Sediment transport directions are indicated by distinctive clasts, such as granitic materials derived from the Holyrood Intrusive Suite which crops out to the southwest (King 1988), or those clasts initially brought to the shoreline by northwestward-flowing glacial ice. Clasts from the Ordovician Bell Island Group, which crops out on Kelly's and Little Bell Islands, are not present, indicating that transport from the northwest is not significant.

Northeastward storms also produce cuspate features on these beaches. The cusps associated with northeasterlies are large and wide (dimensions may exceed 5 m), without seaward lips. The strongest northeast storms (e.g. October 1992) generate overwash along the entire coast, resulting in the formation of overwash fans in the lagoons and damage to coastal infrastructure, vessels, and buildings within 50 m of the shoreline. Taylor (1994) recommended setback limits of 50 m along exposed parts of the Conception Bay South shoreline, based on susceptibility to coastal erosion and the known effects of the 1992 storms; this setback limit may not be sufficient in the event of a stronger storm.

Maintenance of a wide mixed sediment flat is dependent upon suitable offshore bathymetry and onshore topography, and upon a continuous supply of both sand and gravel sufficient to replace any sediment lost through erosion and longshore drift. At both Kelligrews and Chamberlains, the nearshore bathymetry is shallow, allowing longshore currents to move parallel to the shoreline at moderate to low velocities. The bedrock structure consists of a planar to very gently dipping platform of sedimentary rock, with successively younger beds exposed to the northwest (offshore). The Quaternary deposits in the area consist of a series of laterally coalescent glaciofluvial and glaciomarine kames, fan deltas, and terraces, composed dominantly of pebble gravel with lesser quantities of sand and cobbles, with interbedded glacigenic and sediment gravity flow diamictons (Catto1998, Catto and St. Croix 1998). Quaternary deposits border the shoreline from Indian Pond Beach northeastwards to Topsail Cove, and locally stand in 20 m high cliffs. The Conception Bay South shoreline, therefore, had the necessary sediment supply and suitable topographic conditions for the development of wide gravel and sand flats.

Sediment flux to the systems at Kelligrews and Chamberlains has changed since 1941, primarily as a result of anthropogenic activities and secondarily as a consequence of the gradual sea level rise evident along the Avalon Peninsula coastline (Catto 1995, Catto and St. Croix 1998). Study of aerial and ground level photographs taken from 1941 to the present indicate that textural variations, particularly involving periods when more sand was present, were more prevalent 50 years ago than has been the case in the past 5 years. Throughout this period, both shoreline areas have become narrower and steeper, but the trends differ somewhat at the two sites. At Kelligrews, changes in slope are more apparent than changes in width, whereas the reverse is true at Chamberlains.

The sand supply to these systems initially originates from the Quaternary deposits which flank the shoreline to the southeast. The absence of ferruginous sands and granules indicates that sediment is not supplied from Kelly's Island. Coastal erosion and slope failure of the Quaternary bluffs and fluvial transport contribute sediment to the shoreline. Once sand arrives at the shoreline, it is moved offshore and towards the northeast by swash-backwash and longshore currents. Sand gradually accumulates in the offshore areas, and is re-supplied to the shoreline by wave activity associated with northeast or northwest winds. The sand thus undergoes a net northeast movement along the shoreline from Seal Cove to Topsail, as southwesterly winds dominate, but large amounts will periodically be driven southwestward to re-supply beaches at Kelligrews and Chamberlains. Under natural conditions, therefore, these beaches will be supplied with sand both from offshore and from the adjacent Quaternary shoreline outcrops. Shorelines to the northeast were dominated by finer sediments (greater sand: gravel ratio) and were wider than shorelines to the southwest developed under similar geomorphic conditions.

Anthropogenic activity in Conception Bay South, however, has significantly reduced the supply of sand to the shoreline. The replacement of sheep herding and agriculture with suburban development and the diversion and impoundment of rivers has reduced the erosion of inland Quaternary outcrops. Stabilization of the Quaternary bluffs, and extraction of aggregate at Seal Cove (4983-5006), have also reduced influx from the land.

At Kelligrews, the railroad embankment isolates the shoreline from the Quaternary sediment outcrops, causing the shoreline to gradually become steeper and narrower. When the railway was active, periodic re-ballasting of the line acted as an additional source of sediment, but the cessation of operations has ended this influx. The railway embankment today serves as a retaining wall and acts as a coarse back-berm structure, limiting wave overwash and coastal erosion during storm events. This effectively reduces the sand influx available for the beaches to the northeast, such as Chamberlains.

The shoreline northeast of Foxtrap, including the Chamberlains area, is not protected by a railway embankment, and hence is more susceptible to overwash during storms. Northeast winds here act to flatten the beaches, moving sediment inland and forming large overwash fans in the lagoons. The lower, narrower beaches afford less protection to coastal infrastructure surrounding the lagoons. Severe property damage resulted in the Chamberlains and Manuels areas during the storms of September-October 1992, and to lesser extent during autumn 1994. Northwest winds are also effective agents of shoreline modification at Chamberlains, as it is not sheltered by Kelly's Island (as

is Manuels) and is subject to a longer fetch across Conception Bay to the northwest than is Kelligrews.

The Chamberlains area is thus more exposed than is Kelligrews, and is somewhat more susceptible to textural and geomorphic changes. The texture of the Chamberlains flat, however, depends upon sand supply which ultimately originates from the Kelligrews area and those to the southwest. The anthropogenic activity which has reduced sand influx along parts of the Conception Bay South shore has thus had a significant effect throughout the region.

CLASS 17 -- NARROW GRAVEL & SAND FLAT

Class 17 beaches are defined as those dominated by mixed populations of sand and gravel, that are less than 30 m in width. Many Class 17 zones are transitional through both space and time. These beaches may change from narrow gravel and sand flats to wide gravel and sand flats (Class 16; such as Long Pond Beach, tape reference 5125-5138), or to steep sand and gravel beaches (Class 18), or to steep gravel beaches of Class 15. These transitions reflect changes wrought by seasonal events, shifts, or temporary truncations of sediment supply, and isolated major storms.

Examples of Class 17 beaches are located at Coley's Point Beach, Long Pond segment (Harbour Grace map sheet, tape reference 2782-2822; Illustration 16), and Kettle Cove (Bay de Verde map sheet, tape reference 1520). These beaches are marked by substantial seasonal variability in texture and geomorphology. In the late spring and early summer, the Class 17 shores are gently to moderately sloping (slopes 3° -17°), with planar to slightly concave profiles. Planar profiles are more evident in beaches which are not subject to extensive ice foot development (Long Pond CBS, winter 1993-4 along the northwest segment of Coley's Point). Areas where ice foot development has been persistent and has exceeded 30 cm in thickness during the preceding winter (Kettle Cove, northwest Coley's Point in winter 1994-5) are marked by concave profiles in the following spring and summer. Seasonal reworking results in gradually steepening slopes throughout the summer, a process which persists in autumns not marked by strong northeast gales. In these years, slope angles reach maximum values of 10°-25°. Shorelines which are subjected to northeast winds around the autumn equinox develop steep profiles, with stacked tiers of bowl-shaped cusps with seaward lips, produced by shore-normal waves. Cusp back wall slopes can exceed 40°.

Sand proportions are generally greatest in the early summer months, reaching 40 % at Coley's Point and Kettle Cove. Sand supply to Long Pond Beach has been modified due to anthropogenic activity along the Conception Bay South shoreline, and the proportion of sand in this system continues to decline on an irregular basis. All Class 17 shorelines in the Conception Bay region, however, are dominated by pebble gravel.

CLASS 18 -- STEEP GRAVEL & SAND BEACH

Steep gravel and sand beaches develop both seasonally (in association with sand and gravel flats or

gravel beaches), and independently. Class 18 beaches are associated with many spit and barachoix features. They also develop in association with laterally extensive bluffs of Quaternary diamictons and glaciofluvial sediments, as is evident along the Conception Bay South shoreline.

As is the case for the Class 15 systems, seasonal variability is a hallmark of steep mixed sediment beaches. Slopes range from minima of < 5° to maxima of > 25°. Profiles are strongly concave on coarse cobble systems, moderately concave where fine cobbles and coarse pebbles dominate, and gently concave (locally and temporarily planar) where fine pebbles, granules, and sand comprise more than 40% of the textural assemblage. Textural assemblages range from coarse cobble beaches with small amounts of coarse sand (New Melbourne, tape reference 0983-1005) to seasonally granule dominated systems (Broad Cove, tape reference 4380). Cuspate structures are present on the coarsest beaches for at least some period in all years, but are only found on granule and fine pebble beaches for short periods following major storms. Stacked tiers of cusps are evident on photographs of several systems, and are rotinuely encountered in the field.

The steep gravel-sand system at Topsail Beach (tape reference 5170-5180; Illustration 17) has been the subject of investigation by the author and students since July 1989 (Catto and Thistle 1993, Prentice 1993, Catto 1994a, Catto 1995). Topsail Beach represents an example of a coastal system extensively modified by human activity, beginning from the initial settlement in 1820. Major changes in the beach have been affected by sediment mining, interruption of current flow by up-current breakwaters and groynes, changes in land-use practices, damming and regulation of the inflowing streams for hydroelectric power, and recreational usage.

Prior to 1940, Topsail Beach was a broad, mixed sand-and-gravel flat, with sand present in excess of gravel. At the time, it was advertised as "The Brighton Beach of Newfoundland" and "The St. John's Riviera", and had been a major social gathering place since 1843, when it was first linked by road to St. John's. Photographs from 1910-1940 show the beach to have extended more than 20 m seaward of its present shoreline in the outlet area. Based on study of the photographs, the system prior to 1940 would have been described as a shoreline alternating between Class 16 (wide gravel-and-sand flat) and Class 19 (wide sand flat); the limited evidence available suggests that Class 16 conditions were generally prevalent.

During World War II, large quantities of sand and gravel (the precise volumes are unknown or are classified information) were removed from Topsail and other south Conception Bay beaches to construct Torbay Airport and other military facilities in St. John's. The landward part of the back-barrier lagoon is the site of one of the major pits. Additional material was removed directly from the beach front. When extraction ceased in 1943, the beach front was as much as 5 m landward of its present position.

Shifting agricultural and land-use practices, in particular the replacement of sheep herding by suburban development, limited the replenishment of sand to the beach system after 1950. Most of the sand had previously been derived from low bluffs of glaciofluvial and glaciomarine sediments which line the coast south to Seal Cove. Many cliffs were stabilized by armouring with rip-rap and debris (often illegally dumped). Yachting facilities were constructed up-current at Manuels, and

breakwaters designed to protect these funnelled sediment away from the shore and into the deeper parts of the strait between Topsail Beach and Bell Island (the 'Tickle'), thus causing Topsail Beach to be bypassed. The Tickle is underlain by medium and coarse sand throughout much of its length.

Hydroelectric damming of streams entering the coast to the southwest also limited sand supply to the shore. Regulation of the stream at Topsail allowed marine activity to dominate the back-barrier lagoon, and to control the position and time of opening of the outlet. Recreational activity, including all-terrain vehicle use, has enhanced erosion rates along the beach. Along the southwestern margin, the beach has been eroded to the point where storm waves now break against the unconsolidated bluffs, causing substantial erosion.

Glaciofluvial exposures along the Conception Bay coastline are generally subject to constant erosion, punctuated by enhanced removal during storms. During the most recent major storm in the Conception Bay area (early October 1992), as much as 1 m of bluff was eroded from the sediment bluff directly to the southwest of Topsail Beach (Topsail United Church). Further erosion resulted from the autumn 1994 storm events. The removal of sediment from the base of the bluff contributed to mass movement of the upper parts of the exposure, resulting in the systematic collapse of the cliff. Most mass movement activity, however, did not occur in direct association with the storm: severe slope failures did not begin until spring 1995 and have persisted through to December 1995. Slope failures were triggered primarily by disturbance to the vegetation at the crown of the slope. A small fringe of spruce trees which had stabilized the upper part of the exposure for more than 70 years was destabilized by removal of material from the base of the cliff, initiating undercutting and mudflows on the oversteepened slope. The majority of the tree fringe has now been removed, and most of the remaining trees are currently being undercut. Removal of these trees has greatly accentuated erosion of the bluff, resulting in severe retreat.

Along Topsail Beach, these changes have substantially modified the morphology of the beach system. Topsail is now a coarse gravel-dominated beach, characterised by extreme instability of the outlet (several openings and closings on individual days) and high sediment mobility. Sorting varies from good to extremely poor. Seasonal shifts in texture (from coarse in late autumn to finer in early summer) are common in the southwestern part of the system, but do not occur to the northeast (in the vicinity of the outlet).

Major textural changes followed the storms of October 1992 and 1994. The 1992 storm reduced the proportion of sand in the system, and sand supply remained low throughout 1993 and summer 1994. The 1994 storms removed material from the southwestern end of the beach preferentially, but did not significantly alter the texture of the northeastern segment. After the 1994 storm season, sand in the northeastern part of the beach continued to move towards the northeast, but no sand was available from the southwest to replace this material. Consequently, the northeastern part of the system became coarser. During the summer of 1995, sand derived from the failing Quaternary bluff up-current began to replenish the southwestern and central segments of Topsail Beach, resulting in fining textures and lessening intertidal and subtidal slopes. This sand influx began to reach the northeastern part of the beach system in late autumn 1995, unhindered by northeast winds. Topsail Beach thus contains more sand today than at any time since investigations commenced in August 1989.

Sedimentary structures, both small- and large-scale, show considerable spatial and temporal variability (e.g. Prentice 1993). Most segments of Topsail Beach are too coarse to permit the formation of ripples, and the development of small-scale sedimentary structures is confined to short periods of relative quiescence. Ridge and runnel complexes, small cuspate features, and viscous grain flow cones, fans, and sheets marked some pebble-dominated areas during the early summers of 1991 and 1992. Such features are ephemeral, being destroyed and reformed on a daily basis, and few survive the intense reworking characteristic of the late summer and autumn of 1991. The 1992 storms completely obliterated these features, and they were not restored until the late summer of 1994. The autumn 1994 storms resulted in the destruction of the fine pebble features at the southwestern end of the beach, but those in the northeast remained. Newer ridge-and-runnel complexes were constructed at the southwestern end throughout the summer of 1995.

Large-scale gravel cuspate structures, formed by wave activity, are present at various times during the year. The morphology and pattern of cuspate development is highly dependent on local, temporally-varying wave conditions. Cuspate morphology commonly differs throughout the length of Topsail Beach, with shore-parallel transport generally more effective at the southwestern margin, and differs throughout the seasons or in response to individual storm events. Differences also are attributable to elevation above sea level, as different waves strike the shore at different elevations, and so produce different styles of cusps.

Up to six stacked sequences of cusps, reflecting different wave regimes, have been observed on Topsail Beach, and two to three tiers are commonly present. Systematic observations indicate that some cusps remained unaltered for several years, but all were disturbed or reformed during the October 1992 storms. During the 1994 storm event, all cusps at the southwestern end of the beach were somewhat altered, with the highest level (1992) features failing due to undercutting at their seaward margins. At the northeastern end of the beach, the highest cusps formed by the 1992 storms were not altered by the 1994 event. Many of these cusps, however, have been altered by anthropogenic activity, as the northeastern end of the beach is the most accessible and the most heavily frequented.

Gravel cusps give the beach a scalloped appearance, and are marked by shallow depressions, with breadths much greater than widths. The scale of the cusps varies from minimum breadths (along shore) of ± 50 centimetres to maximums in excess of 2.5 m. The widths (perpendicular to shore) range from < 20 cm to 1.5 m, and the depths (crown to base of hollow) range from 5 cm (one clast thickness) to > 1.5 m. Slope angles within the hollows may exceed 45°, but are generally between 12° and 25°. The cusps are asymmetrical in plan view, open to the west-southwest with more steeply sloping and shorter slopes on their northern and northeastern margins. The morphology of these cusps indicate the dominance of shore-parallel transport from southwest to northeast.

Storm waves which overtop the back-beach areas usually produce elongate, linearly-sloping depressions, with width greater than breadth, as the waves overtop the barrier and disperse landward, rather than returning as backwash. A seaward lip is produced where the largest materials are initially dislodged from the back wall of the cusp, but are too large to be transported seaward under wave

power alone. The cobbles move to the base of the cusp under gravity, but then accumulate on the seaward lip as the water diffuses through them without being able to transport the clasts.
Additional examples of Class 18 shorelines are present at Job's Cove and Cull Island (Heart's Content map sheet, tape references 1649-1651 and 16821694), at Broad Cove (Holyrood map sheet, tape reference 4380), and northeast of the Bell Island ferry terminal. Textural and geomorphic features, particularly cusp styles, indicate that wave energy regimes and transport directions differ at each site. Job's Cove is dominated by moderate energy transport, predominantly aligned normal to the shoreline, and marked by reflective conditions and extensive swash activity. Broad Cove is marked by low to moderate energy, shore-parallel transport, and varies between reflective and dissipative in nature. The Bell Island terminal beach is dominated by shore-parallel transport (towards the northeast), but southeasterly winds can generate moderate energy shore-normal swash events. Energy levels at the Bell Island site vary from low to extremely high, and anthropogenic modification of the shoreline is much in evidence. This shore is predominantly reflective in character. As at Topsail Beach, seasonal and yearly variations are evident at all of these sites.

CLASS 19 -- WIDE SAND FLAT
CLASS 20 -- NARROW SAND FLAT

Sand flats are defined as containing less than 30 % gravel of all grades, including granules. The generally coarse texture of the Quaternary sediment, the high energy levels of most of the Conception Bay shoreline, the shortness and steepness of the streams carrying sediment to the shore, the steep bathymetry, the low mesotidal to microtidal regime, and the prevalence of frost wedging all combine to limit the supply of sand to the coast. Sand dominated systems can only develop in isolated areas where some of these factors are locally not involved. Sand flat systems are confined to only two locations in the Conception Bay study region: Salmon Cove (Illustration 18) and Northern Bay Sands (Illustration 19). The Northern Bay Sands area also contains Class 11 and 12 shorelines, and has been discussed previously.

Salmon Cove (tape reference 1932-1945) differs substantially from Northern Bay Sands, as it is a confined littoral system isolated from longshore currents by bedrock headlands. Sand supply here is limited to sediment derived from aeolian dunes, which in turn formed from reworking of preexisting Quaternary glaciofluvial kame deposits exposed along the Salmon Cove River to the east. The sand is transported cyclically onshore and offshore by shore-normal waves, although a much lesser lateral component of motion along the beach is also observed.

Aggregate extraction, residential development, and highway construction have resulted in the removal and covering of most of the glaciofluvial sediments during the previous 20 years, effectively curtailing terrestrial sediment influx to the beach area. The cove is isolated from the prevalent southward longshore drift, and largely from the effect of northeasterly gales, but easterly storms with high wave activity result in the flushing of the cove towards the south. Therefore, the sediment supply within the embayment is strictly limited, and is subject to diminishment over time.

Salmon Cove is an anomaly along the Avalon (and Newfoundland) coast, a sand-dominated, highly reflective coastline. The steep, prominent headlands to the north effectively preclude the southward longshore drift characteristic of northern Conception Bay from influencing the cove, in contrast to the situation at Northern Bay Sands. Sediment transport is dominantly shore-normal, and in consequence cuspate spits, rip currents, and shallow beach cusps are prevalent. A tombolo joins a bedrock island in the centre of the embayment to the mainland.

The structures developed on the beach at Salmon Cove resemble those present in the Lance Cove area of the Placentia Bay coastline (Catto 1994c, Catto *et al.* 1997). The primary differences between the beaches are the slightly greater slope of the intertidal and nearshore areas of Salmon Cove (up to 10°), which allows wave runup to higher positions on the beach face; the lack of longshore drift, which effectively precludes any lateral movement of sand along the beach front; and the greater persistence of ice foot development, which effectively curtails sedimentation from early January to late April.

The beach is dominated by medium-grained sand throughout the year. Rare storm events cause erosion of the base of the dunal complex, but the fine sands are swept seaward and do not form sedimentary features on the beach. Clumps of beach pea act to stablize irregular patches of the beach area up to 1 m in diameter, but are currently suffering degradation from both natural and anthropogenic causes. Currently, beach pea growth covers < 5 % of the upper beach face, and is absent from the lower parts of the supratidal area.

Swash-and-backwash structures and shallow beach cusps indicate that waves approach parallel to the trend of the shore throughout the active period of sedimentation. Ripples present on the beach are generally straight crested, in phase, with narrow crestal platforms, and have stoss and lee slopes of 9-16° and 19-28° respectively. Typical crest-trough heights are 2-5 cm, and ripple indices (Tanner 1967) range between 3 and 8. The internal structures are marked by planar cross-laminations, with sharp but conformable bounding surfaces marked by discose argillite fragments. Diffuse sand sheets frequently cover the beach during higher-energy swash events, but the energy regime is typically low throughout the year.

The dune field at Salmon Cove is extremely restricted, consisting of a single line of shield (modified parabolic) dunes which have coalesced into a transverse complex. The dunal complex originally extended along the length of the beach, but anthropogenic disturbance has resulted in the complete erosion of the northernmost 30 m, and serious degradation over the remainder of the 100 m long complex. The surfaces of the shield dunes are disturbed by numerous blowouts. Grainfall in a niveo-aeolian / moist coastal environment was the dominant process, although reworking was extensive. Little evidence of traction or saltation load deposition is evident. Local deposition and reworking on the dune surface was controlled by short, sharp onshore wind gusts (c.f. Jungerius 1984, McFadgen and Yaldwyn 1984, Pluis 1992).

The coastal dunes developed during the mid-Holocene, in response to lowered sea levels and the availability of supplies of fine and medium sand. Sea level fell steadily during the early Holocene along the Avalon coastline. Glaciomarine and glaciofluvial deposits, developed as a result of higher

sea levels immediately following deglaciation, were thus available for reworking. Delay in the establishment of coastal vegetation along the exposed shores allowed dune construction to progress. Destabilization of coastal environments during the incipient stages of the mid- to late-Holocene transgression (cf. Davidson-Arnott and Pyskir 1988) may have facilitated or enhanced the development of the coastal dune sequence.

Mid-Holocene climate was milder than that of the present, retarding the development of coastal peat veneers and blankets and increasing the influx of terrestrial sediment. Under current climatic conditions, development of aeolian dunes is hindered by the regrowth of vegetation and the blanketing of areas adjacent to the shorelines by terrestrial peat. The dunes are thus essentially relict features, and will not regenerate naturally under the present environmental conditions. At Salmon Cove, a fragment of *Abies* wood underlying the aeolian complex that was exposed by wave erosion in 1992 has been ^{14}C dated at 4250 ± 130 B.P. (GSC-5535). The date thus indicates that dune building began during the latter phase of the mid-Holocene, coinciding with renewed marine transgression.

There is little possibility of replenishment or dune reconstruction should the sand be removed. Current climatic conditions do not favour dunal development. The ongoing marine transgression, if continued, will result in the destruction of the dunes, as the geomorphology of the area does not afford any positions to which the retreating dunes could migrate. The rates of anthropogenic modification of the dunal complex, however, is greatly in excess of the rates of geological modification.

No records are kept at Salmon Cove, an unsupervised Provincial Scenic Attraction, but extrapolation of personal observation suggests that less than 5,000 visits occur annually. The low numbers of visits, however, does not mean that the beach is unaffected by recreational activities. The most significant form of recreational impact on Newfoundland dunal systems is all-terrain vehicle use. All-terrain vehicle usage has had a major impact on almost all the dunal coastlines in the province. In unsupervised areas (especially during the autumn and spring) such as Salmon Cove, the amounts of degradation are striking (locally in excess of 1 metre per year). Aerial photograph analysis has revealed that large increases in the rate and extent of blowout development, dune lowering, and overall degradation have occurred throughout the past ten years. At Salmon Cove, the entire northern end of the dunal complex has been eroded following destabilization, and the northern margin continues to retreat at >2 m / year.

CLASS 22 -- MUDFLAT

Mudflat areas are defined as those shores with a slope < 2°, little or no permanent vegetation cover, surface sediment composed of < 50 % total sand and gravel, and few or no boulders. The majority of the sediment may be either silt, clay, or a combination of both. Mudflats are generally associated with tidal activity in most regions of Atlantic Canada, but this is not a necessary component of the classification. Estuarine deposits formed predominantly by fluvial action, those occupied in whole

or large part by any form of vegetation, and those with boulders on the surface are excluded from this classification. Mudflats are not present in the Conception Bay region.

CLASS 23 -- ESTUARY AND FRINGING LAGOONAL

Estuary and fringing lagoonal areas are defined as those where estuarine conditions prevail, together with marginal areas marked by organic sediments, aquatic or marsh vegetation, or near-stagnant lagoonal waters. Lagoons associated with the back-beach areas of barachoix, tombolos, and similar features are excluded from this classification. Issues involved in definition and classification of potential estuaries around the Avalon Peninsula are discussed at length by Catto *et al.* (1997); also see Fricker and Forbes (1988), Hume and Herdendorf (1993), and Gregory and Petrie (1994).

The only example of an estuarine system where road and railroad construction has not effectively precluded development is located at Riverhead, at the head of Harbour Grace (tape reference 2186-2202; Illustration 20). The most common situation at Riverhead involves mixing of surface fresh water with saline waters, and hence low salinity gradients from surface to depth, coupled with high relative velocities of basal water with respect to surface water. This small estuary is thus categorized by well-mixed conditions during most of the year.

SUMMARIAL ...TRIBUTION OF SHORE CLASSES

Shorelines in the Conception Bay region are dominated by coarse grained gravel deposits (Classes 6, 13, 14, and 15) and cliffed areas (Class 3). Areas with mixed sand and gravel deposits (Classes 9, 16, 17, and 18) are less common than gravelly zones, but dominate some areas of the shoreline, in particular the Conception Bay South area. Narrow exposed rock platform areas (Class 2) are relatively uncommon, and only one example of a wide rock platform shoreline (Class 1) was noted, at Flatrock. Perry's Cove was the only locality where a wide rock platform was overlain by sediment, varying in texture seasonally (Classes 4 and 7). Narrow rock platforms partially covered by coarse sediment (Classes 5 and 8) occur more frequently.

Sand-dominated shorelines (Classes 11, 12, 19, and 20) are confined to only two areas, Northern Bay Sands and Salmon Cove, reflecting the paucity of sand particles in the region. Although some streams supported local estuaries prior to anthropogenic disturbance, Riverhead represents the only Class 23 shore in the region. Shoreline classes not observed include sand flats overlying wide rock platforms (Class 10), steep sand beaches (Class 21), mudflats (Class 22), and bouldery tidal flats (Class 24). These shoreline classes are rarely present along other segments of the Avalon coast, with only single examples of Classes 10, 22, and 24 being recorded along the Placentia Bay coastline (Catto *et al.* 1997). The characteristics of the shorelines with sediment components are summarized in Table 2.

The majority of the beaches along the Conception Bay shore are marked by energy levels of swash waves that are greater than those of the outgoing backwash. Shorelines generally are dominated by

onshore-offshore transport of sediment, with shore-parallel transport playing a lesser role. The influence of shore-parallel transport, however, is much greater than along the Placentia Bay coastline, and is locally dominant in some areas, particularly Conception Bay South. Sediments and contaminants have long residence times within individual coves and embayments marked by restricted longshore transport, but residence times along open coastlines are extremely short.

Seasonal and yearly variability is characteristic of many of the shoreline systems studied along Conception Bay since 1989, and is evident in comparison of the 1981 videotape observations with aerial photographs taken during other years. This variability hinders effective classification of these systems based on a single time of observation. Textural and morphological fluctuations lead to different classifications of the same system in different years, or at different seasons. Variations result from shifts in wind direction, with exposure to northeast winds being the most crucial factor for most shorelines in the region.

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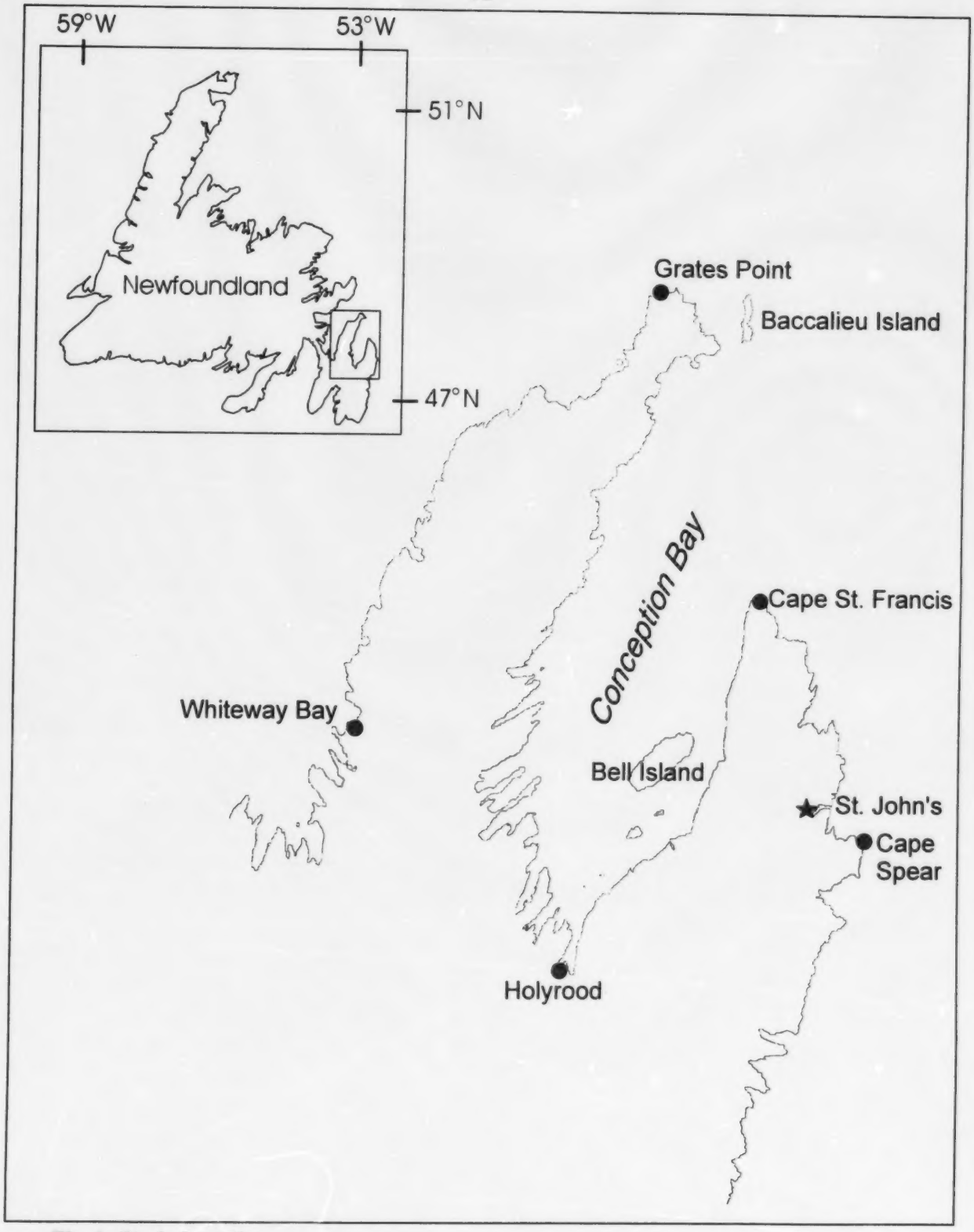


Fig. 1: Study Location

Table 1: Shoreline Classification Scheme for Conception Bay & Adjacent Areas

Class	Substrate	Sediment	Width	Slope	Type	Examples
1	Rock	None	Wide	Low	Wide Rock Platform	Flatrock
2	Rock	None	Narrow	Low	Narrow Rock Platform	Bay de Verde; Island Point; Kingston
3	Rock	None	Narrow	Steep	Rock Cliff	Brigus; Bauline; Flambro Head; Recliff Head; Red Head
4	Rock & Sediments	Gravel	Wide	Low	Gravel Beach on Wide Rock Platform	Perry's Cove
5	Rock & Sediments	Gravel	Narrow	Low	Gravel Beach on Narrow Rock Platform	Kingston; Long Beach; Colliers Pt.; Grates Cove
6	Rock & Sediments	Gravel	Narrow	Steep	Gravel Beach with Rock Cliff	Gallows Cove; Healy's Cove; Hibb's Cove & numerous others
7	Rock & Sediment	Gravel & Sand	Wide	Low	G & S Beach on Wide Rock Platform	Perry's Cove; Spout Cove
8	Rock & Sediment	Gravel & Sand	Narrow	Low	G & S Beach on Narrow Rock Platform	Spout Cove; Biscayan Cove; Bacon Cove
9	Rock & Sediment	Gravel & Sand	Narrow	Steep	G & S Beach with Rock Cliff	Jugglers Cove; Freshwater Cove; Bell Island; Bishop's Cove
10	Rock & Sediment	Sand	Wide	Low	Sand Beach on Wide Rock Platform	none
11	Rock & Sediment	Sand	Narrow	Low	Sand Beach on Narrow Rock Platform	Northern Bay
12	Rock & Sediment	Sand	Narrow	Steep	Sand Beach with Rock Cliff	Northern Bay; Salmon Cove

Table 1 (continued) : Shoreline Classification Scheme for Conception Bay & Adjacent Areas

Class	Substrate	Sediment	Width	Slope	Type	Examples
13	Sediments	Gravel	Wide	Low	Wide Gravel Flat	Bay Roberts; King's Beach; Harbour Grace; Clarke's Beach
14	Sediments	Gravel	Narrow	Low	Narrow Gravel Flat	Grates Cove; Easter Beach; Holyrood
15	Sediments	Gravel	Narrow	Steep	Steep Gravel Beach	Bristols Hope; Caplin Cove; Chapel Cove; Bryants Cove
16	Sediments	Gravel & Sand	Wide	Low	Wide Gravel & Sand Flat	Kelligrews; Chamberlains
17	Sediment	Gravel & Sand	Narrow	Flat	Narrow Gravel & Sand Flat	Coley's Point Beach; Kettle Cove; Long Pond Beach
18	Sediment	Gravel & Sand	Narrow	Steep	Steep Gravel & Sand Beach	Job's Cove; Bell Island Terminal; Broad Cove; Upper Gullies
19	Sediment	Sand	Wide	Low	Wide Sand Flat	Salmon Cove; Northern Bay
20	Sediment	Sand	Narrow	Low	Narrow Sand Flat	Salmon Cove; Northern Bay
21	Sediment	Sand	Narrow	Steep	Steep Sand Beach	none
22	Sediment	Mud	Wide	Low	Mudflat	none
23	Sediment	Organics & Mixed Clastics	Wide	Low	Estuary & Fringing Lagoonal	Riverhead
24	Sediment	Mixed	Wide	Flat	Tidal Flat	none

Table 2: Summary of Shoreline Characteristics

Sedimentary Structures					
Class	**Texture**	**Beach Slope**	**Small Scale**	**Large Scale**	**Stability**
4	Gravel	5° - 15°	None	None	Moderately Stable
4 & 7	Gravel with Sand	10° - 22°	None	None	Moderately Stable
5	Gravel	5° - 20°	None	None	Stable
6 - Enclosed Pocket Beach with High Cliffs	Med. - Crs. Gravel	15° - 40°	None	None	Stable
6 - Enclosed Pocket Beach with Low Cliffs	Medium Gravel	3° - 20°	None	None	Stable
6 - Enclosed Pocket Beach, Stream Influx	Med. - Crs. Gravel	18° - 30°	None	Rare Cusps	Moderately Stable
6 - Open Pocket Beach	(Fine Gravel)	10° - 15°	None	Indistinct Cusps	Moderately Stable
6 - Fringing Beach	Gravel	10° - 45°	None	None	Moderately
8	Gravel > Sand	15° - 30°	None	Cusps	Moderately Stable-Moderately Unstable
9	Gravel > Sand	5° - 25°	None	Rare Cusps	Moderately Stable - Unstable
11	Fine Sand-Granules	<1° - 6°	Planar Parallel Laminae Ripples	Rare Cusps	Moderately Stable

Table 2 (continued): Summary of Shoreline Characteristics

Sedimentary Structures					
Class	**Texture**	**Beach Slope**	**Small Scale**	**Large Scale**	**Stability**
12	Fine Sand Granules	2° - 5°	Ripples	None	Moderately Stable
13	Coarse Gravel	3° - 41°	Offshore Bars	Offshore Bars Cusps	Moderately Unstable
13	Fine Gravel	2° - 18°	Offshore Bars Small Cusps	Rare Cusps Gravel Sheets	Moderately Stable - Moderately Unstable
14	Gravel	2° - 40°	None	Cusps	Unstable - Moderately Unstable
15	High Energy Gravel	8° - 40°	None	Cusps	Moderately Unstable - Moderately Stable
15	Moderately Low Energy Gravel	6° - 38°	None	Indistinct Cusps	Moderately Stable
16	Gravel > Sand	2° - 25°	None	Cusps	Unstable
17	Gravel > Sand	3° - 30°	Ephemeral Ripples	Cusps	Unstable
18	Gravel > Sand	2° - 35°	None	Cusps	Unstable
19	Medium Fine Sand	< 1° - 10°	Ripples, Laminae	Sand Sheets	Moderately Stable - Stable
20	Sand	2° - 10°	Parallel Laminae	Sand Sheets	Moderately Stable

Appendix 1: Location of Selected Shoreline

Tape Reference	Site	Shoreline Class
0000	Whiteway Bay	15
0117	Islington	13/15
0130 - 0185	Heart's Delight	13/15
0270 - 0318	Heart's Desire	15/18
0436 - 0503	Heart's Content	17/18
0580 - 0626	New Perlican	15/18
0665	Turk's Cove	15/18
0690 - 0704	Winterton	15/18
0770	Hant's Head	3
0804 - 0818	Hant's Harbour	14/15
0844 - 0877	New Chelsea	14/15; 14/17; 17/18
0915	Abraham's Head	2
0950 - 0968	Island Point Cove	2; 5
0983 - 1005	New Melbourne	14/17; 17/18
1010	Brownsdale	14/15
1090 - 1100	Perlican Island	2
1100 - 1152	Old Perlican	14/15
1220	Daniel's Cove	14/15
1280	Hearts Cove	2, 3, 5, 6
1290	Grates Point	2
1300 - 1305	Grates Cove	2, 5, 14, 15
1360 - 1363	Red Head Cove	15
1435 - 1445	Backside	2, 3, 5, 6

Appendix 1 (continued): Location of Selected Shoreline

Tape Reference	Site	Shoreline Class
1470 - 1488	Bay de Verde	2, 5, 15
1520	Kettle Cove	17, 18
1530	Low Point	5, 8, 15, 18
1550 - 1562	Caplin Cove	15; 15/18
1575	Flambro Head	3
1596 - 1611	Lower Island Cove	15/18
1649 - 1651	Job's Cove	18
1682 - 1694	Gull Island	18
1710 - 1735	Northern Bay Sands	11, 12, 17, 19, 20
1767 - 1771	Ochre Pit Cove	15
1786 - 1794	Western Bay	15, 18
1816 - 1818	Bradley's Cove	5/8
1830 - 1833	Adam's Cove	5
1848 - 1852	Blackhead	6, 15
1858 - 1862	Broad Cove	15
1887 - 1900	Kingston	2/5
1905	Spout Cove	8
1916 - 1926	Perry's Cove	4/7; 5/8
1932 - 1945	Salmon Cove	12, 19, 20
1975 - 1978	Clements Cove	14/15
1980 - 1989	Freshwater Cove	14/15
2000 - 2066	Carbonear	14/15
2082 - 2096	Bristol's Hope	15

Appendix 1 (continued): Location of Selected Shoreline

Tape Reference	Site	Shoreline Class
2129 - 2234	Harbour Grace	14/15
2186 - 2202	Riverhead	23
2172 - 2178	Kings Beach	13/15; 14/15
2299 - 2305	Bryant's Cove	15
2332 - 2345	Upper Island Cove	15
2362	Bishops Cove	9, 14
2390 - 2403	Spaniard's Bay	14/15
2407 - 2433	Spaniard's Bay (South Side)	13/16; 14/17; 15/18
2531	Jugglers Cove	6, 9
2573	Mercer's Cove	6/9
2600	Coish	15
2782 - 2822	Coley's Point Long Beach	14/15; 17/18
3043 - 3045	Hibb's Cove	6
3054 - 3058	Ship Cove	6/9; 15/18
2932 - 2941; 3100 - 3110	Port de Grave	6/9, 14, 15
3235 - 3306	Clarke's Beach	13, 14, 14/17, 15
3410 - 3476	Cupids	14, 15
3636 - 3640	Gallows Cove, Brigus	3, 6
3652 - 3733	Brigus	3, 6
3840	Turks Gut	6
3905 - 3965	Colliers	14/17
4095	Colliers Point Long Beach	2/5

Appendix 1 (continued): Location of Selected Shoreline

Tape Reference	Site	Shoreline Class
4129	Bacon Cove	3, 8, 15
4225 - 4283	Conception Harbour	15/18
4311	Broad Cove	18
4364 - 4385	Avondale	14/17; 15/18
4493 - 4498	Gallows Cove	6/9
4512 - 4570	Harbour Main	14, 15
4616 - 4638	Chapel Cove	15
4688	Healy's Cove	6
4805 - 4845	Holyrood	14/15
4959 - 4969	Indian Pond	17, 18
4983 - 5006	Seal Cove	17, 18
5030 - 5040	Upper Gullies	17, 18
5050 - 5070	Kelligrews	17/18
5090 - 5125	Foxtrap	17, 18
5125 - 5138	Manuels	17/18
5138 - 5168	Chamberlains	17/18
5170 - 5180	Topsail	18
5239 - 5256	St. Philips	18
5298 - 5310	Portugal Cove	6
5437 - 5442	Bauline	3, 6
5576	Cape St. Francis	3
5585 - 5591	Biscayan Cove	6, 8, 15, 17

Appendix 1 (continued): Location of Selected Shoreline

Tape Reference	Site	Shoreline Class
5622 - 5640	Pouch Cove	15
5650	Shoe Cove	6
5720 - 5730	Redcliff Head	3
5740 - 5752	Flatrock	1
5829 - 5844	Torbay	15
5877 - 5820	Middle Cove	6, 15, 17/18
5890	Outer Cove	6, 15
6113	Logy Bay	3
6344	Cape Spear	3

Illustration 1: Flatrock, Northeast Avalon Peninsula (Class 1)

Illustration 2: Perry's Cove (Class 2)

Illustration 3: Red Head, Flatrock (Class 3)

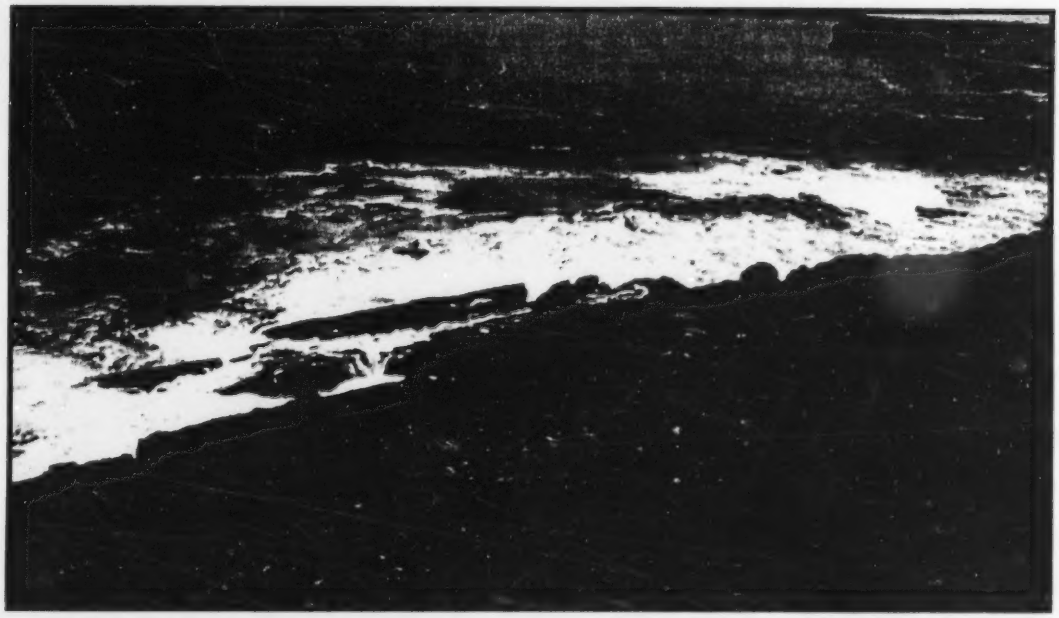


Illustration 4: Near Perry's Cove (Class 4)

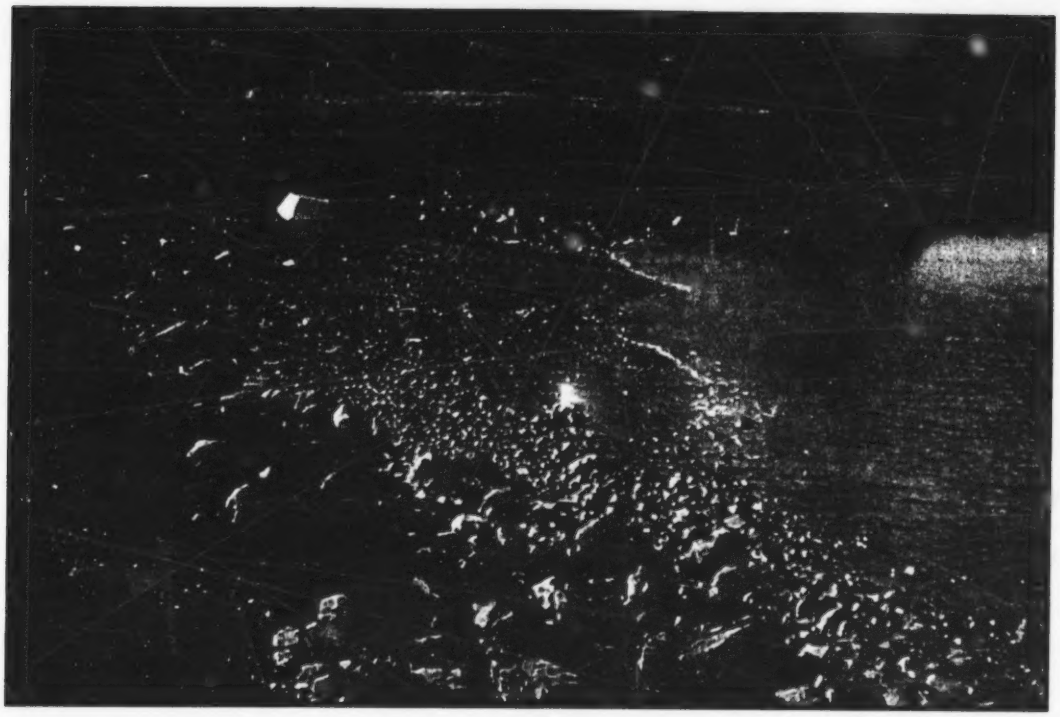


Illustration 5: Collier's Point (Class 5)

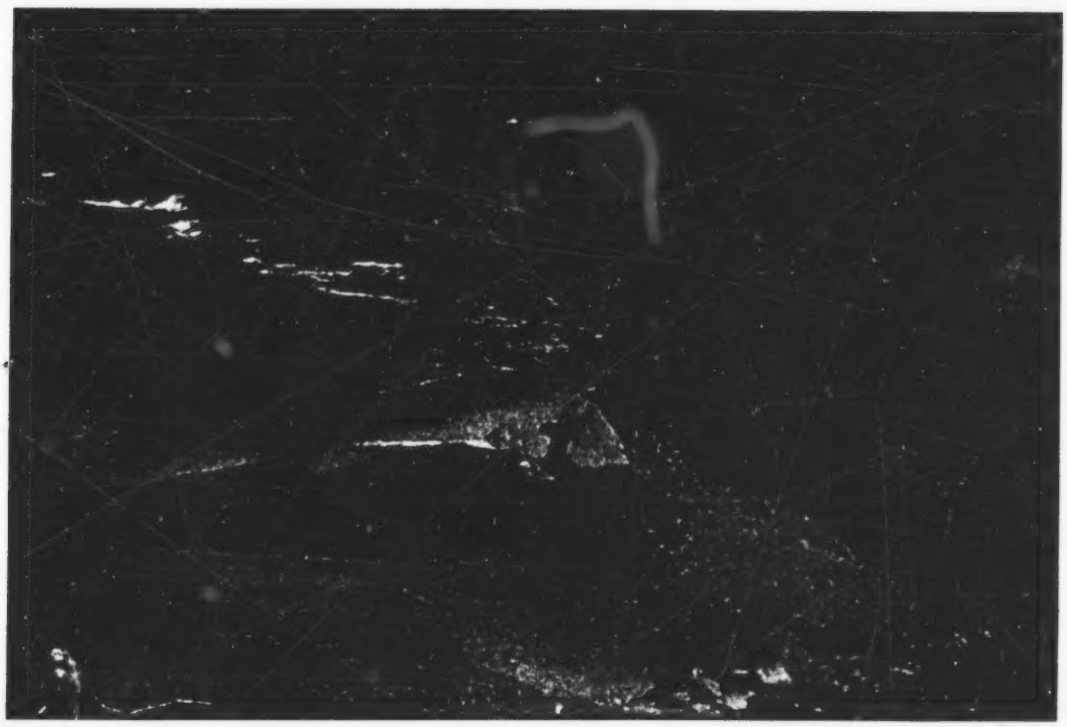


Illustration 6: Shoe Cove, Northeast Avalon Peninsula (Class 6)

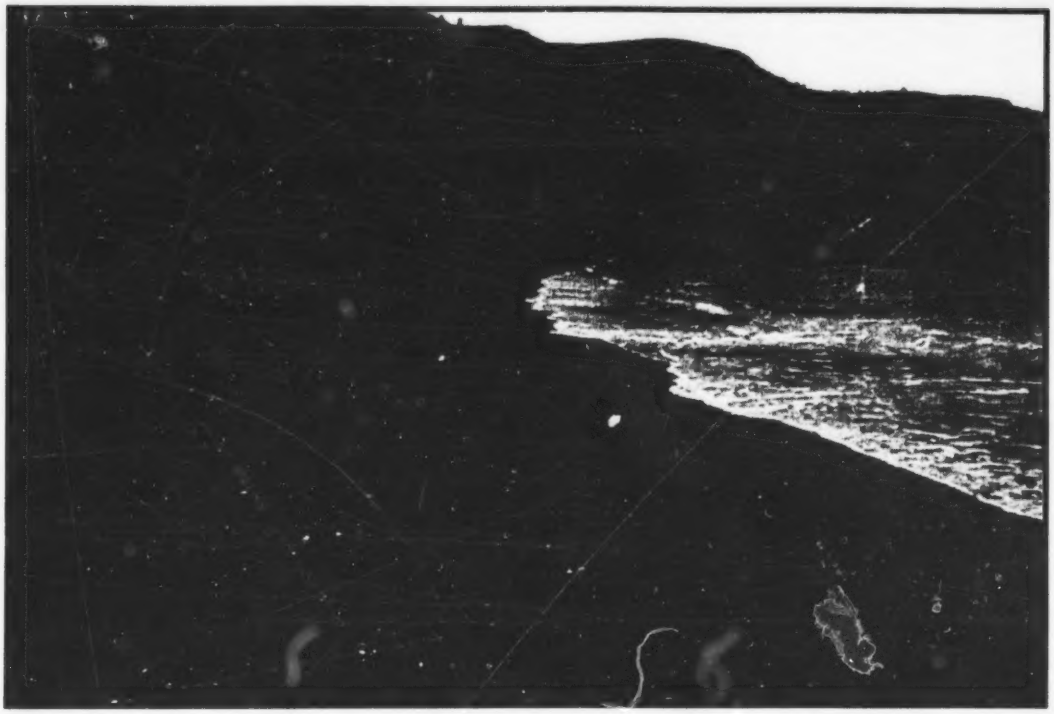


Illustration 7: Southern Segment of Spout Cove (Class7)

Illustration 8: Northern Segment of Spout Cove (Class 8)

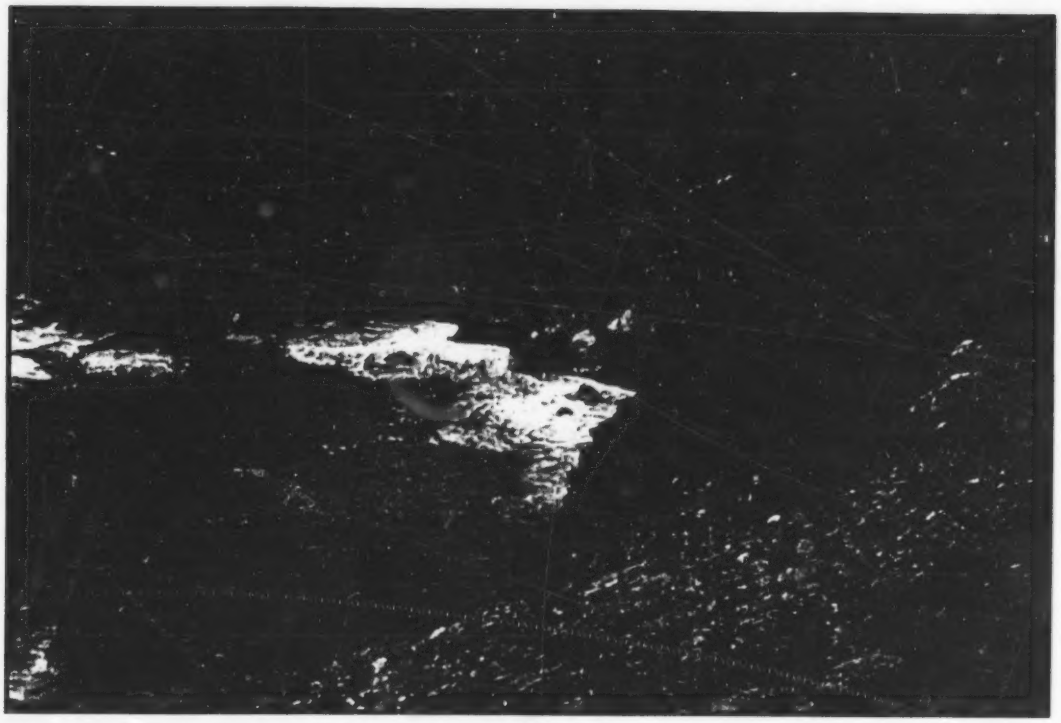


Illustration 9: Jugglers Cove (Class 9)

Note: There was no example of Class 10 in the Conception Bay Study Area

Illustration 10: Northern Bay Sands (Class 11)

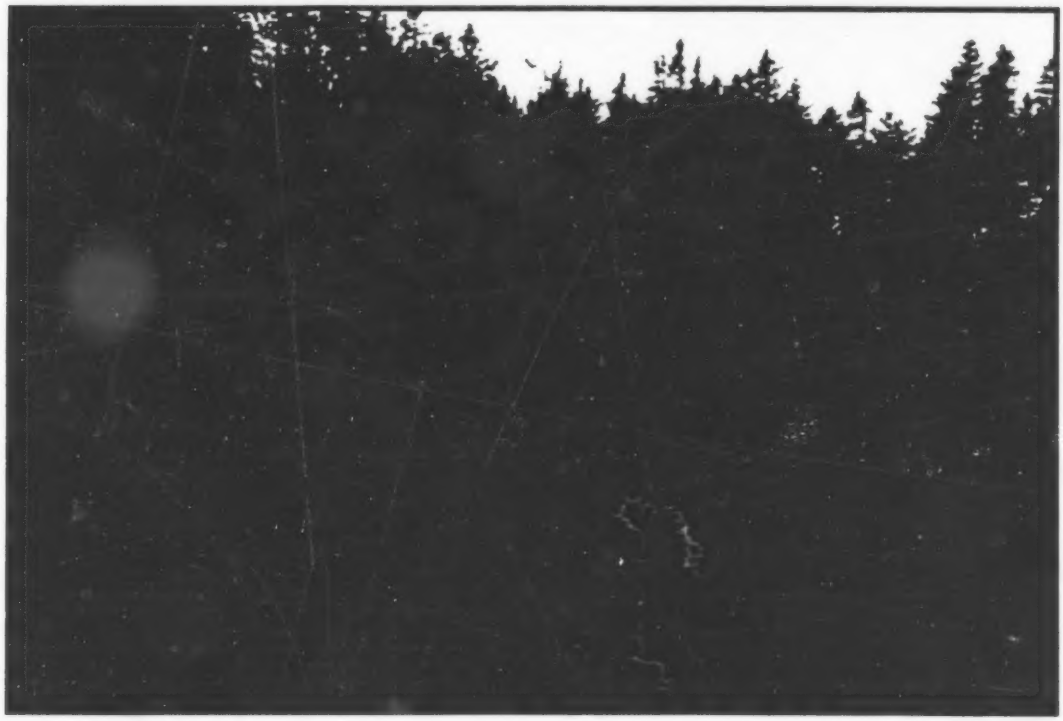


Illustration 11: Northern Bay Sands (Class 12)

Illustration 12: Clarke's Beach (Class 13)

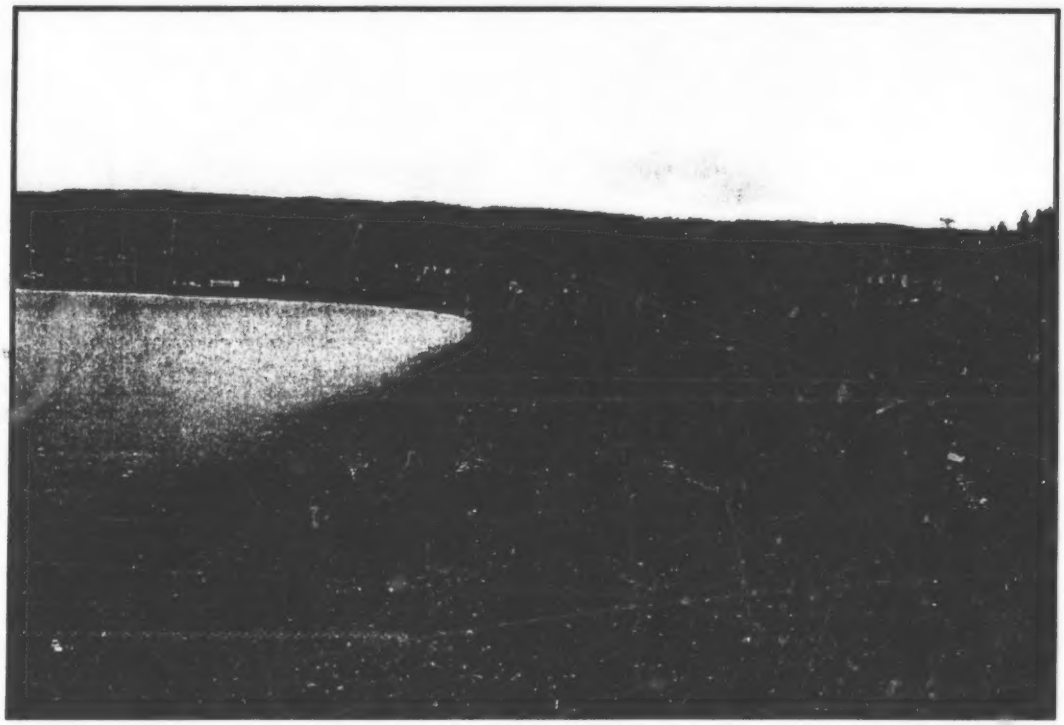


Illustration 13: Holyrood Beach (Class 14)

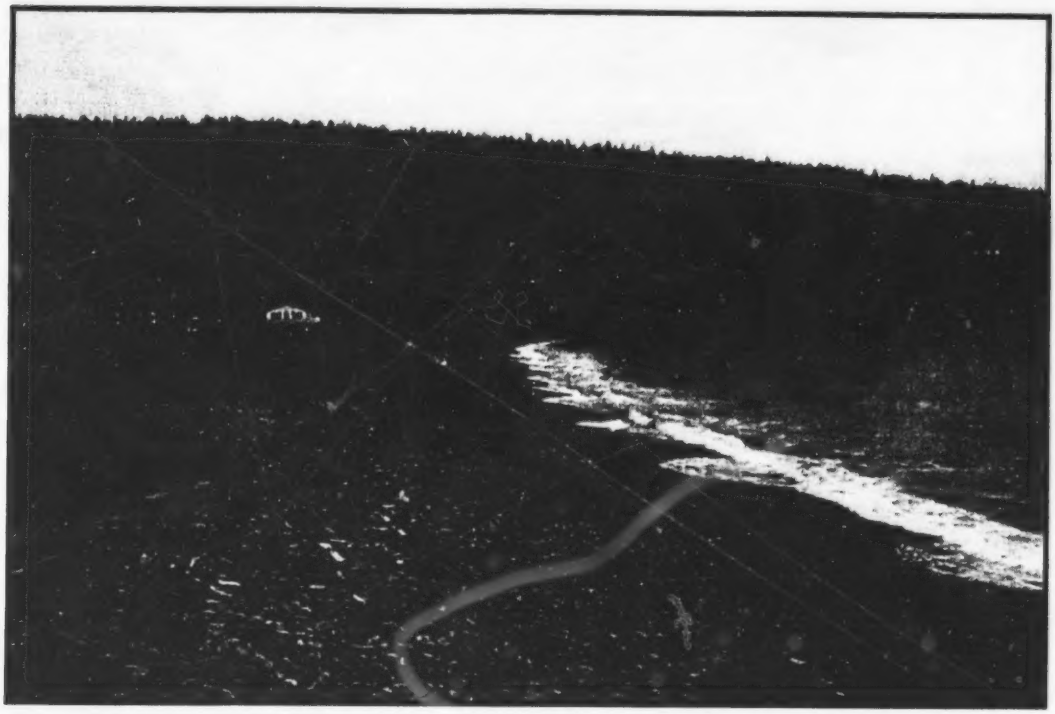
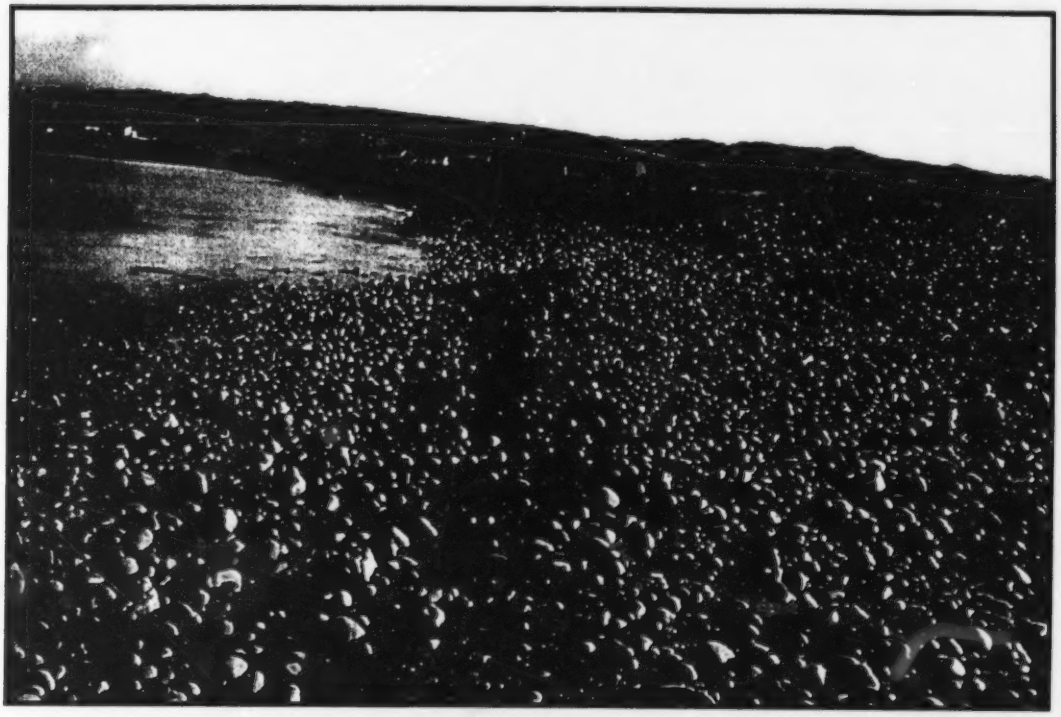


Illustration 14: Bristol's Hope (Class 15)

Illustration 15: Kelligrews (Class 16)



Illstration 16: Coley's Point Beach (Class 17)

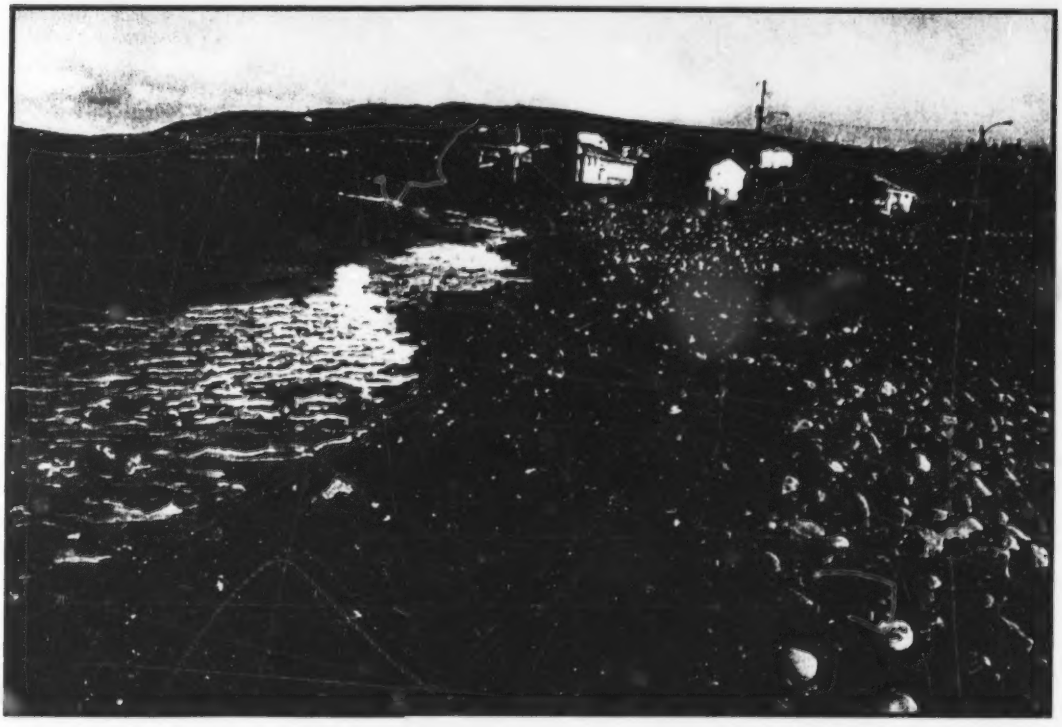


Illustration 17: Topsail Beach (Class 18)

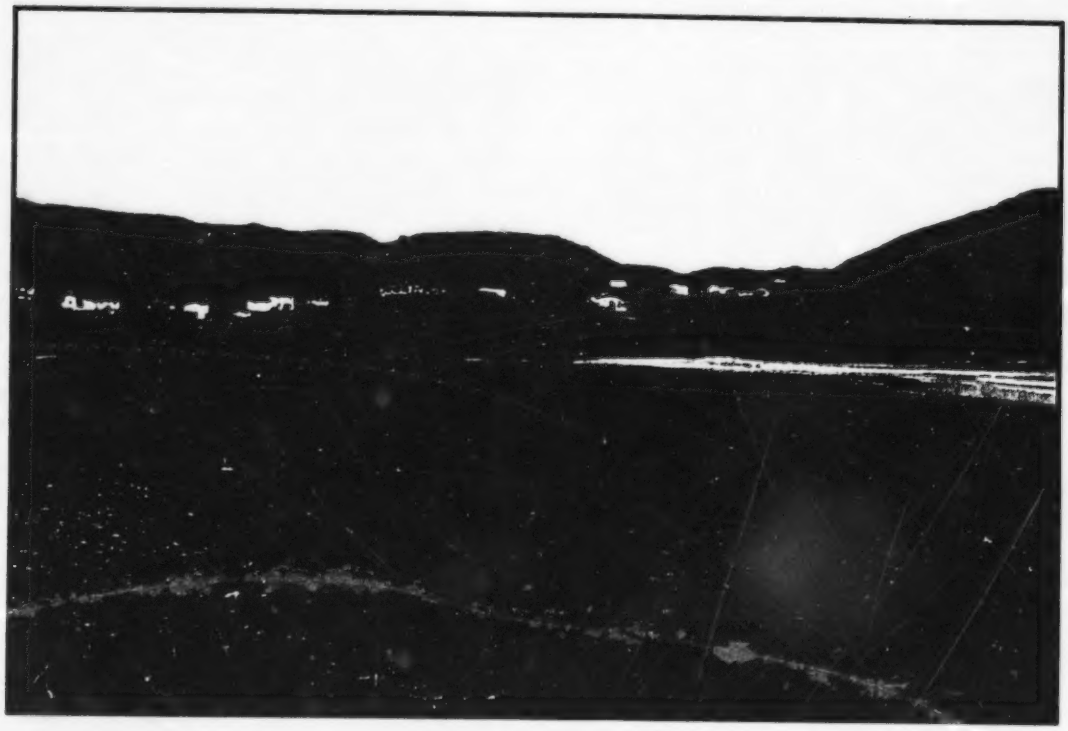


Illustration 18: Salmon Cove (Class 19)

Illustration 19: Northern Bay Sands (Class 20)

Illustration 20: Riverhead near Harbour Grace (Class 23)

Note: There were no examples of Class 21, 22 or 24 in the Conception Bay Study Area.